ACTIVITY REPORT '96

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General

Institute of Information Theory and Automation is a research institute of the Academy of Sciences of the Czech Republic. It is involved with basic research in systems, control, and information sciences.

This report gives an overview of our research activities in 1996. It is of course impossible to give a full account of the research results here. The results selected are divided into sections representing the seven research departments of the Institute. Each department is briefly introduced and its overall activity is described. The report is completed by a list of works published and/or accepted for publication.

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Academy of Sciences of the Czech Republic

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The Institute of Information Theory and Automation (ÚTIA) was established in 1959 as a merger of two academic laboratories: the Department of Information Theory of the Institute for Radioengineering and Electronics and the Laboratory for Automation and Telemechanics.

ÚTIA has been involved with basic research in systems, control, and information sciences. In the 1960s it obtained significant results on the entropy of various sources and on the capacity of information channels with memory. An algebraic approach to control system design was developed during the 1970s which yielded many important results, among which is a parametrization of all stabilizing controllers. The main contributions of the 1980s include a Bayesian approach to self-tuning control, a theory of Rényi distances in probability spaces, and a method of mathematically modelling large-scale gas-distribution networks. Recent developments are in recursive nonlinear estimation and pattern recognition. Currently ÚTIA holds research grants from many domestic and foreign agencies.

The scientific library of ÚTIA contains 30.000 books and periodicals. The computational resources of ÚTIA include an SGI Power Challenge XL computer and a local area network of HP 720 workstations and personal computers. ÚTIA is the administrator of the Academy of Sciences network domain. In 1990, ÚTIA received a major grant from the Andrew W. Mellon Foundation, New York, to upgrade its facilities. In 1996 the Institute started a complete reconstruction and extension of its local area network.

ÚTIA publishes the scientific journal Kybernetika and is the seat of the Czech Society for Cybernetics and Informatics. It regularly organizes the Prague Conferences on Information Theory as well as other events sponsored by the International Federation of Automatic Control (IFAC), International Federation of Information Processing (IFIP), International Association of Pattern Recognition (IAPR) and the Institute of Electrical and Electronics Engineers(IEEE). In 1996 ÚTIA joined the European Research Consortium on Informatics and Mathematics (ERCIM).

ÚTIA has developed close research and teaching contacts with many academic and industrial institutions. It is affiliated with several institutions of higher education, including Czech Technical University and Charles University, and coordinates Central European Graduate School in Systems and Control Theory. It houses the Prague Technology Center, a joint research establishment with Honeywell, Inc. Close cooperation with the Terezín National Memorial and Terezín Initiative (Terezín was the location of a concentration camp and ghetto during WW-2) in the construction of prisoners' database resulted in the publication of Terezín Memorial Book – Vol I. and Vol. II.

The fabrication services of the Institute cooperate with external partners in the fabrication of unique devices. A notebook for visually impaired persons, whose prototype was completed in 1996, attracted public interest.

The Institute organized the

- 2nd ERCIM Workshop on Systems and Control, Prague, August 26 – 27, 1996.
- 2nd IEEE Workshop on Computer–Intensive Methods in Control and Signal Processing, Prague, August 28 – 30, 1996.
- 3rd Conference on Distributions with Given Marginals and Moment Problems, Prague, September 2 – 6, 1996

and participated in the organization of numerous other conferences.

Among others, the following events are under preparation:

- 7th World Congress of International Fuzzy Set Association, Prague 1997.

- Workshop on Statistical Techniques in Pattern Recognition, Prague 1997.
- 13th Prague Conference on Information Theory, Statistical Decision Functions and Random Processes, Prague 1998.

In 1996, an evaluation of ÚTIA was carried out by an international evaluation committee of 16 leading experts in the field. The research results as well as the management of the Institute were found to be in all aspects comparable to similar institutions worldwide.

Contents

1 Department of Decision–Making Theory

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Bernhard Stromeier	–	University of Bielefeld

Grants and Projects:

- R. Jiroušek (principal investigator B. Richards): Managing uncertainty in medicine.
  (Grant EC No. CIPA 3511CT930053, Copernicus)
- J. Outrata: Stochastische Optimierung.
  (Grant DFG No. RO 1006/1-2)
- J. Pik: Discrete event theory application in development of dependable software.
  (Grant GA ČR No. 102/96/1671)
- J. Pik: Complexity reduction methods for discrete event control models and algorithms.
  (Grant GA AV ČR No. 207 5505)
- Z. Schindler: Local and global information network of antibiotic resistance.
  (Grant GA ČR No. 310/96/0588)

- Z. Schindler: The database of Ghetto Terezín.
  (Project supported by Terezín Initiative, Terezín Initiative Foundation and Terezín Memorial)

- M. Studený (principal investigator J. Štěpán): Marginal problem and its applications.
  (Grant GA ČR No. 201/94/0471)

University Courses:

- Faculty of Mathematics and Physics of the Charles University
  - Selected topics of optimization theory.
    (T. Roubíček)
  - Modern optimization theory. (J. Jarušek, J.Outrata)

- Faculty of Applied Sciences of the University of Western Bohemia
  - Systems of perception and understanding. (J. Pik)

- Faculty of Informatics and Statistics of the University of Economics
  - Knowledge representation and processing. (R. Jiroušek)
  - Introduction to informatics. (R. Jiroušek)

- Faculty of Physical and Nuclear Engineering of the Czech Technical University
  - Probabilistic methods in artificial intelligence. (R. Jiroušek)

Our Visitors:

- Prof. P. Dawid (University of London)
- Dr. Ch. Eck (University of Stuttgart)
- Prof. G. D. Kleiter (University of Salzburg)
- Prof. P. Naeve (University of Bielefeld)
- Prof. R. Scozzafava (University of Roma)
- Prof. J. Zowe (University of Erlangen).

Most of the research activities of the department belongs to the field of applied mathematics. We are interested in theoretical problems as well as problems connected with implementation of methods in the following areas:

- artificial intelligence,
- uncertainty processing in expert systems,
- discrete event systems,
- mathematical optimization,
- differential equations.

1.1 Contact Problems with Coulomb Friction

The existence of solutions of *dynamic contact problem with Coulomb friction* was proved for a general viscoelastic body having a smooth contact part of the boundary and a rigid obstacle ([77]). The Signorini contact condition respecting the non–penetrability of mass is formulated for velocities which bounds the applicability of the result to small time intervals and a very small distance between the body and the obstacle. Due to the absolute lack of results published in the field despite its practical importance (there are results only for models which do not respect the non–penetrability of mass or for very special physically unrealistic situations), the existence theorem is the first widely applicable basis for numerical solution of many problems occuring in machinery, civil emgineering etc. The quantification of the bound for admissible magnitude of the (possibly solution–dependent) coefficient of friction leads to a sufficient condition for the existence. Although several optimization procedures were made for its enlargement, it remains rather restrictive. Its improvement, however, will be very hard.

The result was proved via very fine estimates (including the dual ones) in the Sobolev–Slobodeckii spaces together with the interpolation. At first, an auxiliary penalized problem (similar to the normal compliance approach) is solved. To perform the crucial limit procedure to the original problem, a very technical and cumbersome proof of a partial regularity of the solution to the auxiliary problem is necessary. Here, the bound for admissible coefficient of friction is required.

In the *static contact problems with Coulomb friction* the up–to–now proved results of J. Nečas, J. Jarušek and J. Haslinger were sufficiently improved ([26]). The bounds for the maximal admissible coefficient of friction were remarkably extended in all cases and its possible solution–dependence was proved to be admissible for the existence of solutions. The methods of proofs are similar to the preceding case.

1.2 Operators of Composition

Applying probabilistic models in artificial intelligence, the central problem is how to represent probability distributions of very high dimensions. Though it is not expressed explicitly, most approaches utilize the operators of composition introduced below.

Let $\{X_i\}_{i \in V}$ be a finite system of finite sets. We shall deal with probability measures over the Cartesian product space

$$\times_{i \in V} X_i = X_V$$

and its subspaces

$$\times_{i \in L} X_i = X_L$$

for $L \subset V$.

Using the procedure of *marginalization* one can always uniquely restrict a measure P_L defined over X_L to the measure $P_L^{(K)}$ defined over X_K for $K \subset L$. However, it is obvious that the opposite process, the extension of a measure P_K defined over X_K to a measure P_L on X_L is not unique and can be done in many ways.

This is why we introduced the operator of composition whose basic properties are summarized in [177]. We have shown that a wide variety of graph models are nothing else than iterative application of operators of composition. Our results enable to extend the class of decomposable models while preserving all the advantageous properties making the class effective for computations.

1.3 Optimal Design of Topology and Material of Mechanical Structures

One of the basic problems of structural engineering reads: *For a given set of boundary conditions and a given set of loads, find the stiffest structure of a given volume that is able to carry the loads.* Very often, the boundary conditions are given by means of supports or obstacles with which the body is in *unilateral contact*. We studied two variants of the above problem. In the first one, the structure to carry the loads consists of bars that are connected at joints (so-called truss). The design variables are the *bar volumes* and the goal is to choose the volumes (where the total volume is limited) such that the truss becomes as stiff as possible. In mathematical terms we maximize (with respect to bar volumes) the minimal (with respect to displacements) potential energy of the structure.

One can usually improve the optimal truss design by changing the position of the joints. To simulate also this aspect, we work with so-called *ground-structure* approach: We embed the truss into a dense mesh of potential bars and joints, which contains the starting layout and select from this fine mesh an optimal substructure. We equivalently reformulated the problem as a linearly-quadratically constrained program that can be efficiently solved by the powerful interior-point methods [104]. This approach was successively used, e.g., for computation of a real-world example from aerospace industry, in particular, for optimizing the stiffeners in the body of an aircraft [237].

Another way how to improve the design is to optimize the truss *simultaneously* with respect to the bar volumes and to *nodal positions*. This problem have been solved by *separation* of the variables. We formulated the problem as a *bilevel program* which was solved by means of the nonsmooth software (upper level) and interior-point method (lower level) [107].

In the second variant, the wanted structure is a two- or three-dimensional continuum elastic body. The design variables are the *material properties* which, in this approach, may vary from point to point. The objective is the same as in the first approach: we maximize (with respect to material properties) the minimum potential energy, which characterizes the state of equilibrium for a given material under a given load. The problem looks quite complicated at a first glance: in two (three) dimensions, the design variables are the six (twenty one) elements of the symmetric elasticity tensor. But we can analytically reduce it to a problem with only *one* design variable — the trace of the elasticity tensor; in analytical terms this corresponds to the bar volume in the first approach. The elements of the optimal matrix are then fully recoverable from the optimal trace. The reduced problem is discretized by the finite element method to get a mathematical program which is *identical* with that for the truss approach. The only difference is in the character of the input data, namely geometry matrices of bars on one hand and finite element matrices on the other hand. Hence the software developed for the truss approach can be almost immediately used in this framework of material optimization [104].

1.4 Incorrect Observations in Discrete Event Systems

Different kinds of event uncertainty can be found in the analysis, modelling and control of discrete event systems. To deal with uncertainties in actual discrete event systems, processing of noisy, distorted, or incomplete data is required.

Let us consider a discrete event system $\mathcal{G}$ and a supervisor $\mathcal{S}$. Further, let us assume occurrences of event uncertainties that are due to the possibly ambiguous event recognition and/or to the transmission of the event sequences through a noisy channel. As a result of incorrect observations, the supervisor $\mathcal{S}$ observes an event sequence that is different from that of the system $\mathcal{G}$. The distinguished differences are as follows: (i) an actual event is not observed by $\mathcal{S}$, (ii) an observed event is not generated by $\mathcal{G}$, (iii) an actual event generated by $\mathcal{G}$ is observed by $\mathcal{S}$ as a different event.

To model these differences, a general deformation model for discrete event systems has been presented, [172]. Using transformatins of event sequences based on event-to-event operations, an equivalence relation over the set of the event sequences and a corresponding induced partition are defined. Two modifications of the transformation are considered. While the first is based on a stochastic mapping utilizing a probability associated with each event-to-event operation, the second modification introduces the Levenshtein metric for an optimal representation of the event sequences.

1.5 The Database of Ghetto Terezin

The aim of the project is to collect all available data about prisoners of Nazi's concentration camp Terezin and store them in an appropriate database. The official historical documentation as well as other historical sources are not complete and contain a lot of discrepancies. Therefore the database is designed to store all possible versions of data concerning the prisoners of the ghetto and enables discovering inconsistencies.

The use of the database is twofold. The first use is to supply personal data for incomplete or imprecise input information. The database must take into consideration similarity between the data. Then either the most credible data are displayed with the references from where they have been obtained or all probable data are listed with the value of their credibility. The second use is for statistical data processing.

Until now not all the data has been validated; therefore in some cases only less reliable results may be obtained. Historicians continually fill missing data manually. New data after verification and several formal checks are imported to the database. Programs were developed which analyze and filter text files from various documentation centers, extract relevant information from them and generate special files for import to the database. This second approach was used to process fourteen thousand personal records of prisoners from Berlin. This process is semiautomatic - the operator must mark the differences and assign weights to them.

The results of historical research were presented in The Terezin Memorial Book, the second volume of which was printed in the year 1996. The third volume has been in preparation since the beginning of the last year. Also different historical questions were answered using the SQL language tools. Basic statistical tables were generated.

The database is implemented as a relational database, tables of which respect the multivalued information. However, the structure of the relational database is being continually developed to reflect new types of incoming information. In parallel the transfer of the database on technologically higher hardware/software was prepared, as the extent of data exceeded the capabilities of existing hardware.

1.6 Optimization Problems with Equilibrium Constraints

Motivated by the design of transportation networks, a class of mathematical programs with equilibrium constraints (MPEC) has been investigated with partially nonunique solutions on the lower level. This corresponds to a network equilibrium in the sense of Wardrop, where the path flows are rarely unique. By a careful stability and sensitivity analysis we have generalized the successful "implicit programming approach", to this class of MPEC and computed simple test examples. The results are collected in [165].

An effective penalty approach has been developed to the computation of distinguished solutions to a class of quasivariational inequalities and distinguished fixed points of so-called extremal mappings. In this way we can compute eg. the constrained Nash equilibria or various mechanical equilibria with respect to special stress-strain relations. The idea relies on a weakening of the concept of upper Lipschitz multifunction which enables to convert the considered equilibrium problem to an MPEC, solvable by the implicit programming approach. As a test problem, a Cournot-

Nash equilibrium on the oligopolistic market has been computed, cf. [168].

1.7 Conditional Independence and Marginal Problem

Attention was paid to graphical methods of description of conditional independence structures, especially to the class of *chain graphs*. The separation criterion mentioned in [198] enabled us to confirm Lauritzen's and Frydenberg's conjecture concerning chain graphs. More exactly, for every chain graph G over a finite nonempty set of variables N there exists a discrete probability distribution over N which exhibits just those conditional independence statements which can be read from the graph G using the separation criterion. Note that the new separation criterion is equivalent to the original Lauritzen's moralization criterion. As a consequence of this result it was shown that the graphoid properties are complete with respect to the input list of conditional independence statements for chain graphs.

Moreover, in [198], [197] an algorithm is presented which, on the basis of information about conditional independence structure (obtained for example as a result of statistical tests), finds a chain graph describing the structure (provided that such a chain graph exists). The presented recovery algorithm has two stages. At first the so-called *pattern* of the corresponding class of equivalent chain graphs (that is of chain graphs describing the same conditional independence structure) is obtained. After that, the pattern is changed by the application of three specific inference rules into a distinguished member of the corresponding class of equivalent chain graphs which is named the *largest chain graph.*

As to the marginal problem, the research concerned the use of undirected graphs. It was shown in [196] that the class of marginal distributions of Markovian distributions with respect to an undirected graph G over N (that is of marginals of distributions, having the conditional independence structure given by G) for a nonempty subset of variables $T \subset N$ can be equivalently described as the class of Markovian distributions with respect a graph G^T over T which is called the *marginal graph* of G for T.

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Members of the Department organized the 2nd ERCIM Workshop Systems and Control, August 26–27, 1996. There were 35 registred participants from 8 countries. The proceedings [195] include 2 invited papers and 15 contributed papers.

Members of the Department are authors or editors of three books. The book "Control Systems: From Linear Analysis to Synthesis of Chaos" [220] provides a valuable insight into the methods of analysis and design of control systems, with particular emphasis on stability and robustness. A unified approach is applied to the examination of both linear and nonlinear control, using the mathematical framework of dynamical systems with parameters. The monograph "Polynomial Methods for Control System Design" [43] was motivated by a workshop held in conjuction with the 33rd IEEE Conference on Decision and Control.

The proceedings "System Modelling and Optimization" [23] of the 17th IFIP TC7 Conference on System Modelling and Optimization, July 10–14, 1995, organized in Department include 7 invited papers and 67 selected contributed papers.

V. Kučera is the Editor-in-Chief of the scientific journal Kybernetika, published bi-monthly by the Institute. This is a flagship journal of the Czech control and information community and it has a worldwide readership. The journal is monitored by Science Citation Index and its impact factor is 0.156.

One of the major activities in the Department is the coordination and extensive participation in the joint project with Honeywell Inc., USA, called *Prague Technology Center*. This project includes the development and implementation of modelling and control methodology, mainly for home and buildings and industrial automation divisions. Several tasks are solved in cooperation with the Faculty of Electrical Engineering of the Czech Technical University in Prague.

There exists also a collaborative research and numerous informal contacts with foreign universities and scientific institutions. Members of the Department made twenty three visits to abroad including four for an extended period of time.

Grants and Projects

J. Doležal, Computation Optimization of Nonlinear Dynamical Systems – Methodology, Implementation and Applications (Grant Agency of the Czech Republic);

J. Doležal, Prague Technology Center (Honeywell);

V. Kučera, Methods and Algorithms of Robust Control (Grant Agency of the Czech Republic);

V. Kučera, Théorie des Systèmes Linéaires et non Linéaires (CNRS France);

V. Kučera, Dynamic Control & Management Systems in Manu-

facturing Processes (European Community – Copernicus);
V. Kučera, Structure of Linear Systems (Tübitak-Doprog, Turkey);
M. Šebek, Algorithms for CAE Based on Modern Polynomial Methods in Control (European Community – Copernicus);
A. Vaněček, Global Stabilization of Nonlinear Systems (Grant Agency of the Academy of Sciences of the Czech Republic);
A. Vaněček, Nonlinear Stabilization (Grant Agency of the Czech Republic).

Teaching Activities

V. Kučera, Faculty of Electrical Engineering of the Czech Technical University: Algebraic Approach to Control System Design (postgraduate).
P. Zagalak, Catholic University, Chile: Linear Systems (postgraduate).
P. Zagalak, CINVESTAV, Mexico: Linear Systems (postgraduate).

Our Visitors

V. Eldem, Marmara Research Center, Turkey
D. Henrion, Engineer School INSA Toulouse
F. J. Kraus, ETH Zürich
H. Kwakernaak, University of Twente, Enschede
J. J. Loiseau, Ecole Centrale de Nantes
J. C. Martinez Garcia, CINVESTAV del IPN, Mexico City
R. Ortega, Laboratoire des Signaux et Systèmes, CNRS, France
W. Ratemi, University of Alfateh, Libya
R. Sivan, Technion – Israel Institute of Technology, Haifa
J. Torres, CINVESTAV del IPN, Mexico City

PhD Project Successfully Completed

Faculty of Electrical Engineering of the Czech Technical University
J.J. Ruiz León: Decoupling of Linear Systems [181]
Supervisor: P. Zagalak

Representation in International Societies

J. Doležal – President of the Czech Committee for IFIP and Full Member Representative in IFIP General Assembly;

V. Kučera – Vice President of IFAC and Chairman of its Technical Board;
– President of the Czech Committee on Automatic Control;
– Fellow of IEEE and a member of the IEEE Control Systems Society Board of Governors;

M. Šebek – A member of the IFAC Policy Committee;
– President of the Czech IEEE Control Systems Society Chapter

The research objectives in the Department of Control Theory are primarily in the analysis, optimization and design of control systems. Two main research directions are as follows:

- analysis and design of linear systems including $\mathcal{H}_2$, $\mathcal{H}_\infty$ optimization and robust control;

- simulation and optimization of nonlinear systems including linearization, nonlinear feedback control, and parameter optimization.

Interest is focused on both theoretical studies and computer implementation of the results obtained.

2.1 Partial Model Matching

The problem of model matching consists of compensating a given linear system so that the resulting system is stable and has a prespecified (model) transfer function. This is a hypothetical control problem which covers many cases of interest, including the design of a servo with desired closed-loop dynamics and the design of disturbance rejection / attenuation control systems.

An exact match is difficult to achieve. A less stringent design specification, the so-called partial model matching, is sufficient in many practical situations. It consists of matching a prespecified number of the first Markov parameters rather than the entire transfer function.

The problem is solved in two steps. First, a dynamic cascade compensator is found which achieves the match. The effect of the compensator is then realized using a feedback law.

Two types of feedback are considered: static state feedback [125] and dynamic state feedback [124]. Necessary and sufficient conditions are obtained for partial model matching to be possible using each of the two types of feedback compensation. All admissible compensators are parameterized. The degrees of freedom are then used to optimize the match.

The design flexibility offered by the partial model matching is remarkable. In addition, the requirement of stability for the closed-loop system is not a limiting factor when dynamic state feedback applied. On the other hand, stability requirement does restrict the solution in the case of static state feedback.

This research was supported by the Grant Agency of the Czech Republic under contract 102/94/0294.

2.2 Delay-Differential Systems

These are linear time invariant systems built from blocks of two types: integrators and delayors. A special class of them is with commensurate delays: all delays are multiples of some T. The transfer functions of these systems are rational functions of two variables: s, e^{-Ts}, satisfying the condition of causality and properness: $F(s)$ is finite for $Re\ s \to +\infty$. As functions of s, they are meromorphic. Their properties are similar to those of rational functions but the number of zeros and poles may be infinite.

The discretization of these transfer functions for a commensurate sampling period has been derived in explicit form [78]. The resulting discrete transfer functions $G(z)$ are meromorphic function of z^{-1} with a new type of singularity: the accumulation point of zeros or poles. For non-neutral systems, such point is only $z = 0$.

This research was supported by the Grant Agency of the Czech Republic under contract 102/94/0294.

2.3 Algorithms for Polynomial Matrices.

New computational methods have been developed to solve a symmetrix matrix polynomial equation

$$A(s)X^T(-s) + X^T(s)A^T(s) = 2B(s),$$

with given $A(s)$, $B(s)$ and unknown $X(s)$. This equation is frequently encountered in various problems of control theory and design. Using poynomial matrix interpolation or reduced Sylvester resultants application, the original equation is transformed into a standard system of linear equations for which reliable and efficient solvers are available. In contrast to its predecessor , the new methods are therefore numerically stable.

2.4 Software for Polynomial Control Design

In the on-going project developing a package [206] of MATLAB macros for polynomial control design (*Polynomial Control Toolbox*), the following progress has been achieved.

New program modules have been added that include new routines for linear matrix polynomial equations of various types `axb`, `axbyc`, `xab`, `xaybc`, `axybc`, `axxa2b`, `axya2b`, `daxxa2b`, `daxya2b` and for symmetric spectral factorization `pjsf`.

Several other special programs have been developed [205] to perform e.g. Kronecker product of polynomial matrices, joint ad to a polynomial matrix, Hermite and staircase forms. First versions of graphical programs have been created to animate the operations with polynomial matrices via nice color 2-D and 3-D plots.

The research is a joint project with the University of Twente, NL, *Algorithms for CAE based on modern polynomial methods in control* supported by the European Community Grant Copernicus No. CP:2424/93.

2.5 State-space Methods for Polynomial Matrix Computations

A polynomial approach to $\mathcal{H}_2$ and $\mathcal{H}_\infty$ robust control design requires reliable numerical algorithms for polynomial matrix operations, such as the solution of various polynomial matrix equations including polynomial matrix factorizations. The present research is aimed at system theoretic algorithms for polynomial matrix computations, [127]. The algorithms rely on constant matrix calculations using well proven algorithms from numerical linear algebra. More than often, polynomial matrix to state space conversion is needed in [127]. A state-space algorithm for polynomial matrix to state space conversion is based on [111]. The algorithm does not require any computation of polynomial matrix operations, e.g. to bring the polynomial matrix to its reduced form before the actual conversion commences.

In the polynomial matrix to state space conversion algorithm, a rectangular polynomial matrix with less than maximal column rank, typically a row-like matrix, is converted to an externally equivalent state-space realization. The conversion exploits *strong observability* in the sense that a system matrix associated with a strongly observable realization has no finite zeros and may be compressed to a unimodular matrix flanked by zeros. Computationally, the algorithm constructs an orthogonal basis for the largest *output-nulling controlled invariant* subspace of a certain strictly proper realization and transforms this subspace into an *invariant subspace*. The transformation requires computation of an orthogonal complement to the subspace basis. The above computations run twice. For the second time they apply to the dual form of the description obtained in the first run. The dual form of the result from the second run is one (straightforward) step ahead of the desired state-space realization.

The conversion is implemented in MATLAB, Version 4.2c. Recently, the conversion has been used in a state-space algorithm for the row-reduction of a polynomial matrix. More recently, an essential part of the conversion algorithm is used in a state-space algorithm for spectral factorization of a para-Hermitian matrix with no zeros on the imaginary axis.

The research is a part of an EC-funded COPERNICUS project in cooperation with Prof. Huibert Kwakernaak, University of Twente, Department of Applied Mathematics.

2.6 Damped Algebraic Riccati Equations

In the last year, extensions to an algorithm to produce dampening controllers based on a periodic formulation of Hamiltonian system were elaborated. Central to this research is a complex-valued formulation of the symmetric and skew-symmetric Damped Algebraic Riccati Equations (DARE) [56]. The solution of these DAREs may be used to produce a state feedback for a standard linear system which not only stabilizes, but also dampens the closed-loop system dynamics. In other words, a feedback gain vector may be computed via the DARE such that the eigenvalues of the closed-loop state matrix are within the region of the left half-plane where the magnitude of the real part of each eigenvalue is greater than the imaginary part. We have shown that this result can be extended to two families of DAREs which may be parameterized by a scalar. The first family is produced by a convex combination of real symmetric and skew-symmetric solutions of the symmetric and skew-symmetric DAREs. The second family is produced by introducing a complex scaling in the constituent Hamiltonian associated with the aforementioned DAREs. Taken together, the algorithm proposed provides a method of choosing a variety of feedbacks which produce a closed–loop system with varying degrees of dampedness and stability. Recently, new and more powerful techniques have been developed for producing dampening controllers. Not only do they provide a means of continuously varying the dampening parameter in the algorithm, but also produce feedbacks with much lower norms. Finally, a simple aerodynamic model has been derived with which to investigate properties of these techniques.

This research was supported by the Grant Agency of the Czech Republic under contract 102/94/0294.

2.7 OptiA Optimization System

The optimization system **OptiA** developed at the Institute enables the solution of both nonlinear mathematical programming and nonlinear optimal control problems [22]. The recent major developments include the option of the so-called automatic differentiation [29] using the PADRE2 algorithm of K. Kubota. Automatic differentiation is strongly competitive with either analytical evaluation of gradients/derivatives or various numerical formulas.

The prototype version of MS Windows implementation of the system was fully implemented in object oriented C++ programming language and tested [31]. It runs in any MS Windows environment including Windows'95 and Windows NT. In a similar way also X-Windows version was implemented [30] for IRIX operating system. Its portability to other UNIX platforms was tested on HP-UX operating system. Thus the existing DOS implementation of the **OptiA** system are accompanied by fully analogical versions running in graphical environments.

This research was supported by the Grant Agency of the Czech Republic under contract 102/94/0645.

2.8 Mathematical Model of HIV Infection

Current developments of the mathematical model of $CD4^+$ lymphocyte depletion (responsible for the HIV infection) were reviewed and summarized for a review paper [62] to bring this topic closer to non-technical readers. In addition, its application to model-based analysis of available therapeutical schemes was continued. Results relevant to immunotherapy and chemotherapy are described in [63]. They show the applicability of the model for effect analysis of drug dosage schedules.

This research is performed jointly with the Institute of Molecular Genetics of the Czech Academy of Sciences.

3 Department of Adaptive Systems

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Head of Department:

Miroslav Kárný – Bayes decision making

Secretary:

Jaroslava Hradcová

Research Fellows:

Josef Böhm	–	robust control algorithms
Alena Halousková	–	design of adaptive control
Jiří Kadlec	–	parallel signal processing
Petr Klán	–	simple adaptive controllers
Rudolf Kulhavý	–	recursive nonlinear estimation
Jaroslav Maršík	–	simple signal-based adaptivity
Petr Nedoma	–	software engineering
Jan Schier	–	parallel adaptive control

Postgraduate Students:

Luděk Berec	–	model structure identification
Jiří Rojíček	–	robust control design
Ludvík Tesař	–	nonlinear recursive estimation
Markéta Valečková	–	dynamic Bayesian nets
Tatiana V. Guy (CEGS)	–	hybrid controllers
Nataša Khailová (CEGS)	–	fault detection
Hong Gao (CEGS)	–	Markov neural nets
Ladislav Jirsa	–	statistics in biophysics

The activities of the Institute fall into cybernetics and informatics, into the fields dealing with analysis and design of systems generating predictions, making decisions or controlling other systems. Unlike ordinary systems, the adaptive systems are able to modify their behaviour in correspondence with the changing environment. This essential feature enhances their efficiency while performing the tasks listed above.

The Department has been active in this area for decades and has obtained significant conceptual, theoretical, algorithmic, software and application results. Through these years the Bayes-based theory of sequential decision making under uncertainty has become fixed, and successful, methodological kernel of our work. We have passed all standard periods of a new research: a little bit naive initial enthusiasm, accumulation of a real know how with signs of external recognition of the achieved results and the period when everybody says that the field is exhausted and out of fashion. In our opinion, we have crossed this critical point, we observe a renewed interest in our field and we are solving qualitatively new problems with a reasonable degree of success.

The interplay between theory and (always limited) computing power is a leitmotiv of our current work. We aim at a significant widening applicability of theoretically well grounded adaptive systems.

The account presented is naturally incomplete. No activity report can fully reflect information contents of tens of papers, of seminars and discussions with partners in academe as well as applied sectors. It is intended as an invitation to meet us, to enjoy creative and friendly atmosphere that we count as our important achievement, too.

Grants and Projects

The results described in the next sections would have been difficult to obtain without substantial support from the variety of sources. The following list of grants and corresponding agencies should be taken as an acknowledgment of this support.

- J. Böhm – *Adaptive and predictive control with physical constraints* (Copernicus CP94-1174 Predcon)
- J. Heřmanská, (M. Kárný) – *Objective evaluation of data measured for diagnostic and therapeutic purposes in nuclear medicine* (GA ČR No. 312/94/0679, successfully concluded)
- J. Heřmanská, (M. Kárný) – *Quality assurance for processing of data measured for diagnostic and therapeutic purposes in nuclear medicine* (EU COST OL B2.20, successfully concluded)
- J. Kadlec – *New structures of distributed control systems for production tools* (GA ČR No. 102/95/0926)
- M. Kárný – *Adaptive dynamic elements and their interconnections for dynamic decision making under uncertainty* (GA AV ČR No. A2075606)
- R. Kulhavý – *Global approximation of model in recursive Bayesian estimation* (GA AV ČR No. A2075603)
- R. Kulhavý – *Efficient method of non-linear recursive estimation: theoretical background and application to selected models* (GA ČR No. 102/94/0314, successfully concluded)
- R. Kulhavý – *Qualitative and analytical model based fault detection for chemical processes* (Copernicus CP94-01320)

- J. Maršík – *Micro-controller framed innovative technology: instruments for adaptive process control* (Copernicus CP93-9630, successfully concluded)
- P. Nedoma – *Adaptive systems: theory, algorithms and software for practice* (GA ČR No. 102/97/0118)
- P. Nedoma – *Enhancement of the EU decision support Rodos and its customization for use in Eastern Europe* (Copernicus INCO PL 963365)
- J. Schier – *Fast parallel algorithms for adaptive identification and LQG control design*
(GA ČR No. 102/95/1614)
- J. Schier – *PTT and OTT Enhancement (POET)* – subproject of the Collision Avoidance Radar (Colarado) Project, STW grant agency (the Netherlands) grant DEL 22.2733
- J. Schier – *Systolic arrays of processors for identification of systems with varying structure* (GA ČR No. 104/93/0927, successfully concluded)
- O. Vašíček (R. Kulhavý) – Modelling of transitive economics using short data samples (GA ČR No. 402/96/0902)

University Courses

Education as an integral part of the research process is reflected in a relatively high number of postgraduate students taught in the Department as well as in supervising several MSc theses and undergraduate research projects. The interest of students is mostly stimulated by the regular undergraduate courses held by the Department:

Faculty of Physical and Nuclear Engineering,
Czech Technical University:

Adaptive Control (Kárný); *System Identification* (Kulhavý)

Faculty of Electrical Engineering,
Czech Technical University:
Estimation and Filtering Theory (Kulhavý)
Faculty of Transportation,
Czech Technical University:
Principles and Applications of Parallel Computation (Kadlec)
Faculty of Chemical Technology, University of Pardubice:
Automatic Control Theory (Klán)
2nd Medical Faculty, Charles University:
Basic Theory of Data Processing (Jirsa)

An international dimension in teaching has been reached through the activities in "*Central European Graduate School in Systems and Control Theory*" (CEGS) established by ÚTIA together with the Czech Technical University, Computer and Automation Institute of Hungarian Academy of Sciences and the University of Western Bohemia.

Conference Organized by the Department

CMP'96, the 2nd European IEEE Workshop *Computer Intensive Methods in Control and Signal Processing* (about 70 participants, the next CMP'98 will be in Budapest; preprints [8] are available, proceeding are in print, Birkhäuser, Boston).

Foreign Guests

Ing. T. Guy, Kiev Polytechnic, (Ukraine), *Ing. H. Gao*, *Ing. D. Bo*, (People's Republic of China), *Ing. N. Khailová* (Russia) study various aspects of adaptive systems within the framework of the *Central European Graduate School in Systems and Control Theory* (CEGS) we are organizing.

Prof. K. M. Hangos, SZTAKI, honorary member of the Department, has been closely cooperating with us for many years.

She is a welcome guest any time. Her recent visits were related to organization of CEGS and to the Copernicus project on Model based fault detection.

Dr. P. Fox, Univ. of Warwick, GB visited our Department last year. His visit was related to CMP'96 where we had opportunity to discuss mutual relationships of selftuners and simple and adaptive controllers as well as other important aspects of life.

Prof. K. Warwick, Univ. of Reading, GB has also been closely cooperating with us for many years. This year he devoted his precious time to the organization of CMP'96 and to the preparation of a joint ESPRIT project as well as joint publications.

Prof. R. Gorez, Catholic University of Louvain visited our department in February in order to coordinate the Copernicus project CP93-9630.

Travel and International Cooperation

Thanks to the support from various grants, PhD students were given opportunity to visit Oxford, Reading, Brussels and Budapest. Coordination and working visits were mostly related to major European Community projects Copernicus.

L. Berec:
research; Copernicus CP94-1174, Oxford University, UK
study visit; Royal Technical Institute, Stockholm, Uppsala University, Linköping University, Sweden
workshop; Copernicus CP94-01320, Ljubljana, Slovenia

J. Böhm:
coordination; Copernicus CP94-1174, Bratislava, SK
summer school; Copernicus CP94-1174, Oxford, UK
study visit; Copernicus CP94-1246, Grenoble, France
CESA Multiconference; Lille, France

J. Kadlec:
research visit; University of Leuven, Belgium

development of software tools for fast prototyping;
Alpha Data, ltd. Edinburgh
information meeting; EU Esprit centre, Brussels
M. Kárný:
summer school; Copernicus CP94-1174, Oxford, UK
research visit; SZTAKI, Budapest, Hungary
research visit; Reading University, UMIST, UK
P. Klán:
research; Copernicus CP93-9630, Glasgow, UK
research; Copernicus CP93-9630, Louvain la Neuve, Belgium
R. Kulhavý:
IFAC World Congress; San Francisco, USA
coordination; Copernicus CP94-01320, Brussels, Belgium
coordination; Copernicus CP94-01320, Piran, Slovenia
P. Nedoma:
coordination; Copernicus INCO PL963365, Karlsruhe, Ger
coordination; Copernicus CP94-01320, Brussels, Belgium coordination; Copernicus CP94-01320, Ljubljana, Slovenia
summer school; Copernicus CP94-1174, Oxford, UK
J. Rojíček:
research; Copernicus CP94-1174, Oxford, UK
J. Schier:
research; Colarado project, TU Delft, The Netherlands
World Transputer Congress; Harrogate, UK
L. Tesař:
workshop; Copernicus CP94-01320, Balaton Lake, Hungary
coordination; Copernicus CP94-01320, Ljubljana, Slovenia
research; Copernicus CP94-01320,
Laboratoire d'Automatique, Université Libre Bruxelles, Belgium
H. Gao:
study visit; the CEGS partner Computer and Automation Institute, (SZTAKI), Hungarian Academy of Sciences, Hungary

RESULTS

The subsequent summaries should give you a rough picture on the results achieved. For more information contact the relevant persons whose e-mails are given under the heading.

3.1 Non-Standard Adaptive Systems

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Markov chains seem to be an excellent alternative to standard regression models (ARX) when constructing adaptive blocks dealing with non-linear/non-Gaussian systems. They are universal, may describe any bounded non-linearity and fit to digital nature of the information processing. Their dimensionality is the only, but serious drawback, for their practical use. For this reason, approximations are searched for. In [60], the dimensionality is decreased by restricting the influence of the modelled-system memory. A long-memory model is constructed by pooling several models with short "regressors".

The dimensionality caused by the number of possible levels of data is addressed in [214]. Essentially, continuity of the underlying sampled system is exploited so that the number of estimated parameters is decreased substantially without loosing simplicity of estimation.

A combination of both mentioned ideas is now elaborated and promises a counterpart ARX model suitable to a wide class of non-linear systems. It will be used in a non-traditional control design [86] that takes probabilistic description of the systems as the basic object to be controlled and leads to a more tractable control design.

A progress has been made even for linear description of controlled systems. A hybrid concept (continuous model vs. digital treatment) has been addressed from a non-traditional perspective [45]. Essentially, the involved sampled signals are approximated by splines and approximants are used both in estimation and control design parts of the adaptive controller. The resulting controller uses standard blocks of linear Gaussian quadratic (LQG) controllers. However, it works on specially filtered data. The finite-impulse response filters result directly from the spline approximation approximation chosen, i.e. from the properties of the observed signals. A high-quality adaptive controller is expected to be gained from this research.

3.2 Extension of Bayesian Identification Theory

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Infinite complexity of the reality and limited descriptivity of the artificial world of models have to be taken into account when modelling any real system. On the other hand, the Bayesian identification theory principally assumes that the “true” object model is contained in the set of model candidates. The analysis [10] tries to break such contradiction. It answers the question: “What is the outcome of the Bayesian identification when a mismodelling is present?” It shows that the best projection of the true description of reality is learnt. It specifies what the notions “best projection” and “true description of reality” mean.

The cited conceptual paper has a direct practical link to the problem of structure estimation addressed in [9]. This paper introduces three qualitatively different types of parameters which together describe uniquely any model in any given model set. The first two parameters describe just the structural part of the model, the third one parameters in a common sense. Using this, Bayesian model structure identification task is formulated. In this framework, the problem of control period selection is also solved in [9]. It exploits the ever present mismodelling and is fully justified only in connection with the conceptual problem discussed above. Verification of the control period selection algorithm is being performed on a coupled-tanks system.

3.3 Computer-Aided Design of Adaptive Controllers

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Adaptive LQG controllers proved their full scale applicability. Their efficient implementation is, however, far from being trivial. For this reason, an ambitious project of their computer-aided design was launched several years ago. Nowadays, a software system DESIGNER is available [152, 153, 154] for solving a full range of the design tasks.

The progress made recently can be characterized as follows.

Structure estimation. The problem has been studied in a wider context (see above) and a more efficient algorithm for searching of the maximum a posteriori probability estimate of the structure has been implemented. Extensive tests are also carried out in order to finalize algorithms that include prior information. The intermediate results seem to be promising. The algorithms facilitate solution even in the cases of poorly informative data [44].

Prior information. A novel approach to data-based construction of the prior distribution [208] has been proposed. It uses ideas of approximate estimation based on information measures (see paragraph on estimation and information measures).

A way how to complete several "deterministic" relationships into a complete probabilistic model is proposed in [87]. The task can be viewed as an interpolation problem in the space of probability density functions. The model gained belongs to exponential family. Its moments fit to the pre-specified relationships.

Event driven control synthesis. A recently proposed novel control design treats a multi-input multi-output system as a set of coupled designs for single-input single-output systems. The corresponding algorithmic solution is presented [11]. It

– makes the design event-driven,
– exploits fully a fine structure of the models,
– handles efficiently multi-rate control.

Optimization of the closed-loop properties. The Monte Carlo algorithms evaluating and predicting closed-loop quantities (like input-output ranges, overshoots etc.) were proposed and implemented. They form a basis for input penalization design in the regulation and tracking problems with desired range of inputs or their changes. An adequate sequential stopping rule that guarantees practical feasibility of the problem is being extended to other critical quantities (like prescribed overshoot). A possibility to use substantially better starting point implied by a new interpretation of weights [178] is considered.

3.4 Parameter Estimation & Information Measures

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While the general theory of recursive Bayesian estimation of dynamic models is well developed, its practical implementation is known to be restricted to a narrow class of models, typically models with linear dynamics and normally-distributed noises. The theoretically optimal solution becomes infeasible for nonlinear and/or non-Gaussian models and needs to be approximated. It is worth stressing that design of such approximation is much harder in the Bayesian case than it is in point estimation. While in point estimation we are interested only in finding a certain point in the parameter space, in Bayesian estimation we compute a whole function of the unknown parameter: likelihood, posterior density or another related object.

A long-term research effort has resulted in reformulation of the probability-based estimation as a problem of probability matching [115, 116, 117]. Estimation is regarded here as a process of measuring a certain information "distance" between the empirical and theoretical distributions of the observed data. Since in recursive estimation data are always compressed using some statistic, it was proposed to measure the minimum "distance" between the set of all distributions consistent with the statistic value and the theoretical density. The approximation is supported by the Pythagorean geometry of probability distributions and the large deviation theory. The scheme makes it possible to calculate, given compressed data, an approximate likelihood or posterior value for an arbitrary parameter value by solving a convex optimization problem.

The use of Kerridge inaccuracy rather than Kullback-Leibler distance in terms of the information measure has made it possible to approach in a unified manner the case of independent, identically distributed observations as well as controlled dynamic systems, both discrete and continuous.

Besides providing a theoretical framework for systematic approximation of Bayesian estimation, the information-based view of parameter estimation has already yielded several practically interesting results, namely

– explaining the dual nature of exponential and linear forgetting and its practical ramifications [119]

– showing the possibility of dual specification of prior information in Bayesian estimation, taking information about either model parameters or observed data,

– proposing an approximate on-line implementation of Generalized Likelihood Ratio tests for non-linear/non-normal models.

3.5 Fast and Parallel Algorithms

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Algorithmization allowing fast and parallel computations extends substantially the applicability range of adaptive systems, e.g. [183]. The key progress made can be described as follows.

– Fast parallel algorithms for identification of systems with unknown structure have been implemented on parallel transputer network [85]. They are robust with respect to poorly informative data due to regularization [85].

– A fixed point predictive controller with enhanced use of regularization scheme has been developed [84].

In the standard approach, the regularization attracts the identification to a vector of parameters representing the prior knowledge about the plant. The basic idea of the proposed controller is to extend this idea. The prior estimate of the plant corresponds to an optimal controller which can be computed in advance. The covariance regularizing matrix is constructed in a form reflecting the prior guess of controller parameters. Using this scheme, one can control the level of adaptation provided by the controller. In one extreme, the controller behaves as the standard LQG predictive controller with exponentially weighted RLS identification. In the other extreme, the controller is completely attracted after each step of identification to its priors and behaves as a constant linear discrete controller. The path between these two extremes is smooth due to the adopted scheme. The fixed point formulation of the controller results in a code ideal for low cost controller and signal processor implementations.

3.6 Tools for a Fast Prototyping

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The speed with which a prototype of a modern algorithm can be implemented becomes a decisive feature under current competitive environment.

This observation has stimulated the DESIGNER project reported above. At the software side an interpreter D*lab* has been developed as a driving device for the DESIGNER and similar projects [150]. For user's convenience, the program system is MATLAB (MathWorks) compatible, written in the form of M-functions and C-coded MEX-functions, packed into objects with interactive interfaces. It serves as a base for cooperation with industry, as a software tool for postgraduate education and as a research experimental environment.

A MATLAB version of the system is available [152, 150].

A significant progress has been made in the active field of automated port of code from Matlab level to parallel hardware based on DEC Alpha AXP architecture. This is one of the key tools for the discussed concept of rapid prototyping and encapsulated code design. The Matlab Compiler enables the user to create C functions from the interpreted Matlab code. The major part of these functions can be recompiled for the DEC Alpha or transputer parallel platforms. This is possible due to the development of libraries emulating the original runtime libraries requested by the compiler. The package was presented at two industry/education oriented Czech conferences (Humusoft, Honeywell Prague Technology Center) and in [151].

3.7 Multi-Model Fault Detection

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Within the Copernicus project CT94-0237 a Matlab toolbox for fault detection and isolation is being prepared. In addition to well established techniques it will contain original contributions of all partners involved. In this direction, our department concentrates on multi-model and multi-forgetting approach. Essentially, several models corresponding to non-fault and various faulty states are run in parallel and compared using Bayesian system classification. In this way, reliable fault detection/isolation is achieved. The considered models may vary from white to black box type models. For poorly understood processes, the comparison of ARX models identified with various forgettings and/or regularizations are especially attractive (both because of simplicity and universality).

3.8 Algorithms for Collision Avoidance Radar

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Within the STW project DEL 22.2733, algorithms for fast target detection for multi-static radar are being developed [185, 184]. The goal of the project is to develop this radar as a sensor for an autonomous vehicle (which can be a cart in an automated production plant). The advantage of the multistatic radar over the solution with an antenna array is simplified design of hardware part of the device.

The algorithms process information on radial distance of the targets from the antennas, measured in several points of 3D space. Each target generates T R-tuples of integer numbers, where T and R are the numbers of transmitters and receivers, respectively. To estimate the position of the target in 3D space, possible R-tuples are generated and compared for T-views of the scene. An incremental algorithm which exploits relatively static character of the scene for the given sampling rate has been developed. The incremental approach to the solution reduces significantly computational complexity of the detection and satisfies the real-time requirements of the system. Bayesian methods has been successfully applied to improve reliability of the detection and to reflect its probabilistic character. Simulation environment has been developed to test the performance of the method and to facilitate its port to the parallel computing system.

3.9 Non-Linear Estimation Tasks in Nuclear Medicine

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The strength of the Bayesian estimation methodology becomes visible when a high estimation quality is required using a few uncertain data and a vague but non-trivial prior information.

We have used our estimation and modelling art in order to contribute to reliable estimation of various quantities inspected in nuclear medicine. They are mostly related to the dynamics of accumulation/elimination of ^{131}I [58, 59]. Programs for estimation of several important quantities were developed [57]. These estimates add modelling and prior information to the patient examination data. This approach decreases significantly the uncertainty of the estimates. Furthermore, it makes it possible to quantify the uncertainty of the results (in contrast to the practice in nuclear medicine). The algorithms are connected to the database system that manages completely the patient's data.

The resulting programs are practically tested in the treatment of thyroid gland diseases. The developed methodology and algorithms have, however, much wider application area, e.g. [215].

4 Department of Stochastic Informatics

Head of Department:

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Assistant:

Iva Marešová	–	tel. 6605 2466, e-mail: stochinf@utia.cas.cz

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Petr Lachout	–	weak convergence of probability measures, asymptotic theory of random processes and fields, robust statistics e-mail: lachout@utia.cas.cz
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Antonín Otáhal	–	random processes and random fields, stochastic methods in signal and image processing e-mail: otahal@utia.cas.cz
Jan Šindelář	–	theory of complexity and its application in probability and statistics, alternative theories of data processing e-mail: sindelar@utia.cas.cz
Petr Tichavský	–	system and signal theory, in particular sinusoidal modelling and high-resolution spectral analysis e-mail: tichavsk@utia.cas.cz
Igor Vajda	–	information theory, mathematical statistics e-mail: vajda@utia.cas.cz
Jan Ámos Víšek	–	robust statistics, regression analysis, adaptive statistical methods, statistical computations e-mail: visek@utia.cas.cz
Petr Volf	–	survival analysis, nonparametric regression, smoothing methods, statistical reliability testing e-mail: volf@utia.cas.cz

Postgraduate Students:

Lucie Fialová	–	applied information theory
Martina Pavlicová	–	spectral theory of random processes.

Conferences:

Twelve lectures, two of them invited, have been delivered at international conferences, including

COMPSTAT'96, Barcelona, Spain

Fourth Bernoulli Congress, Vienna, Austria

Third European Congress on System Sciences, Rome, Italy

European Economic Association Eleventh Annual Congress, Instanbul, Turkey.

Grants and Projects:

M. Janžura: "Gibbs states and probabilistic methods in the theory of phase transitions" (GA ČR, 202/96/0731, 1996–1998).

M. Janžura: "Statistical distances of random fields" (GA AV ČR, A 1075601, 1996–1997).

J. Michálek: "Maximum likelihood principle and I-divergence" (GA ČR, 201/96/0415, 1996–1999).

A. Otáhal: "Minimum entropy of error principle" (GA ČR, 201/94/0321, 1994–1996).

I. Vajda: "Optimal decision, classification and coding with the aid of neural networks." (GA ČR, 102/94/0320, 1994–1996).

I. Vajda: "Global statistical information and consistency of point estimates", (GA AV ČR 175/402, 1995–1996).

I. Vajda: “Research on ATM", (COPERNICUS’94 — European Research Project 589, 1995 – 1997).

J. Á. Víšek: “Empirically optimized choice of the procedure for regression model identification” (GA ČR 201/94/0233, 1994 – 1996).

International Cooperation

Members of the Department participated in joint research with their colleagues from Universities in

- Yale, USA (Prof. A. Nehorai)
- Los Angeles, USA (Prof. A. Swami)
- Baltimore, USA (Prof. A. Rukhin)
- Baltimore, USA (Prof. J. Šmíd)
- Freiburg, Germany (Prof. L. Rüschendorf)
- Rostock, Germany (Prof. F. Liese)
- Madrid, Spain (Prof. D. Morales, L. Pardo, M. Menedez)
- Extremadura, Spain (Prof. A. M. Rubio, F. Quintana, L. Z. Aguilar)
- Paris 7, France (Prof. F. Comets)
- Leuven, Belgium (Prof. E. van der Meulen)
- Stockholm, Sweden (Prof. T. Koski)
- Uppsala, Sweden (Dr. P. Händel)
- Budapest, Hungary (Prof. L. Györfi)
- Michigan, USA (Prof. V. Fabian, H. Koul)
- Wayne, USA (R. Z. Chasminskij)
- Vilnius, Lithuania (Prof. V. Paulauskas, A. Rachkauskas)

- Delft, Netherlands (Prof. J. van der Weide)
- Berlin, BRD (Prof. W. Römisch)
- New York, USA (Prof. M. Padmanabhan)
- Ascona, Switzerland (Prof. E. M. Ronchetti)
- London, U. K. (Prof. M. Landsbury)
- Madrid, Spain (Prof. E. Sentana)
- La Plata, Argentina (Prof. C. Muravchik)

The results of this cooperation are summarized in the published papers [2], [14], [46], [55], [54], [68], [131], [147], [148], [149], [169], [180], [190], [209], [47], [216] and in other 8 accepted and 11 submitted.

University Courses

Fifteen courses on subjects related to the research field of the department were read.

Charles University — Faculty of Mathematics and Physics:
Probability and mathematical statistics, Statistics, Sequential and Bayesian methods (M. Hušková); Probability theory, Advanced parts of econometrics (P. Lachout).

Charles University — Faculty of Social Sciences:
Econometrics, Probability and mathematical statistics,
Statistics (J. Á. Víšek).

Czech Technical University — Faculty of Physical and Nuclear Engineering:
Probability and statistics (I. Vajda, J. Michálek), Information theory (I. Vajda, M. Janžura); Statistical Analysis of Data (J. Á. Víšek); Stochastic systems (M. Janžura)

Technical University Liberec:
Mathematical Statistics, Elements of probability theory (P. Volf).

As part of teaching activities at the above Universities, sixteen diploma projects and 9 doctoral theses were supervised, 3 habilitation theses refereed.

I. Vajda was a member of Scientific Boards of the Faculties of Electrical Engineering and of Physical and Nuclear Engineering.

Researchers of the Department were members of six different boards for defenses of doctoral theses at the Charles University and Czech Technical University.

Research Activities

The Department concentrates on mathematical research in the following areas.

a) Information in statistical experiments and optimal statistical decisions (estimation, testing, classification), with emphasis on maximum entropy, minimum divergence methods, and asymptotic theory.

b) Robust statistical procedures and their applications in various statistical environments, including adaptivity and self-organization. Regression analysis.

c) Statistical inference in random processes and random fields. Applications in stochastic optimization, change-point, optimum investment portfolios, and image and speech processing.

Altogether 49 papers have appeared during 1996. Twelve others have been accepted for publication and 30 papers have been submitted.

4.1 Maximal Likelihood Principle and I–divergence (Jiří Michálek)

In the monograph "Information Theory and Statistics" due to Kullback published at the beginning of the sixties one can find a very interesting relation that concerns a maximal likelihood estimate of an unknown parameter and I-divergence between two probability measures where one of them is determined by the value of the MLE in question. This relation expresses a very close connection between the likelihood ratio maximum and I-divergence. Kullback deals with the i.i.d. case only and with the exponential family of probability distribution functions. The present results concern this interesting relation in general and discuss its possible applications in statistics. First, we deal mainly with the discrete time case, then this relation is proved in the case of Gaussian processes. It is shown that in the case of mutually independent random variables generated by exponential family probability distribution the corresponding likelihood ratio maximum can be expressed using I-divergence and MLE, but in the case of dependent Gaussian random variables forming a stationary sequence or a random process the likelihood ratio maximum is closely connected with the asymptotic I-divergence rate expressed by the corresponding spectral density functions. This relation can be used in the construction of likelihood ratio tests, parameter estimates and detection of changes in unknown parameters. The asymptotic behaviour of a likelihood ratio maximum is studied too.

4.2 Analysis of Generalized Residuals in Hazard Regression Models (Petr Volf)

A counting process (i. e. a process registering the observed events) is considered. We introduce a method of the goodness-of-fit test for hazard regression models. The method is inspired by the explorative diagnostic procedure presented for instance in Arjas (J.A.S.A. 83, 1997, 204–212) and based on the martingale-compensator decomposition of the counting process. Arjas dealt with graphical method for assessing the fit of Cox's model. Later on, the large sample properties of Arjas' statistics were examined by Marzec and Marzec (Scand. J. Statist. 20, 1993, 227–238). The main objective of the present work is to generalize these results concerning both graphical and numerical procedures and, in such a way, to derive a universal approach to goodness–of–fit testing in the framework of hazard regression models.

Let a model be given by a nonspecified (bounded and smooth) hazard function depending on values of an input covariate process $\boldsymbol{X}(t)$. If $N(t)$ denotes the counting process and $L(t)$ corresponding cumulative intensity, the difference $L(t) - N(t)$ is the residual process. The graphical testing of validity of a model (represented by $L(t)$) is based on plot of $L(T_k)$ against $N(T_k) = k$, where T_k are observed times of counts. We show that a method is applicable to quite general models. We also examine the large-sample properties of residuals. It is shown that the aggregated residual process, properly normalized, converges to a centered Gaussian process with independent increments. While this general result is of a theoretical value, it can be specified for cases of selected hazard regression models. We consider also the case when (a part of) the model is estimated from the data. Naturally, the behavior of the residual process then depends on properties of estimators. In order to demonstrate it, we prove the large sample properties of the (normalized) residual process for the case of Aalen's hazard regression model. As a consequence the statistics of the Kolmogorov–Smirnov type is derived. A simple example with simulated data illustrates the usefulness of both graphical and numerical (large-sample) approach to assessing the goodness-of-fit of hazard regression models.

4.3 Posterior Cramér–Rao Bounds for Adaptive Discrete–time System Identification (Petr Tichavský)

We deal with a mean-square error lower bound for adaptive parameter estimation, which is formulated as a discrete-time nonlinear filtering problem. This problem arises in varied applications such as adaptive control, analysis and prediction of nonstationary time series, etc. As is well known, the optimal estimator for this problem cannot be built in general and one is forced to turn to one of the large number of existing suboptimal filtering techniques and to approximate the optimum performance by lower bounds. Lower bounds give an indication of performance limits and consequently can be used to determine whether performance requirements are realistic or not.

In time-invariant statistical models, a commonly used lower bound is the Cramér–Rao bound (CRB), given by the inverse of the Fisher information matrix. In the time-varying systems considered here the estimated parameter vector has to be treated as random due to the assumption of random parameter increments. A lower bound analogous to the CRB for random parameters was described in the monograph *Detection, Estimation and Modulation Theory* due to Van Trees.

The Cramér–Rao theory has been applied to scalar discrete-time nonlinear dynamical systems already by Bobrovsky and Zakai (IEEE Trans. on AC, 20, 1975, 785–788) and Galdos (IEEE Trans. on AC, 25, 1980, 117–119), see also the survey paper due to Kerr (IEEE Trans. on AES, 1989, 590–600).

In our approach the posterior CRB for the multidimensional discrete-time nonlinear filtering problem is derived from its first principles and is more general than the previous bounds. The new bound was calculated for tracking slowly varying AR parameter, tracking slowly varying sinusoidal frequency and tracking lowly varying frequency which is modulated like a sinusoid. The bound appears to have a great potential for choosing a model of data, selecting model order, and evaluating performance of existing suboptimal methods of nonlinear filtering.

Let x represent a vector of a given data, θ be an r-dimensional estimated random parameter, $p_{x,\theta}(X,\Theta)$ be the joint probability density of the pair (x,θ), and $g(x)$ be an estimate of θ, a function of x. The PCRB on this estimate has the form

$$V \stackrel{\triangle}{=} \mathrm{E}\left\{[g(x)-\theta]\,[g(x)-\theta]^T\right\} \geq J^{-1}, \tag{1}$$

where ^{T} denotes the matrix transposition and J is the $r \times r$ (Fisher) information matrix with the elements

$$J_{ij} = \mathrm{E}\left[-\frac{\partial^2 \log p_{x,\theta}(X,\Theta)}{\partial\Theta_i\,\partial\Theta_j}\right] \quad i,\, j = 1,\ldots,r \tag{2}$$

provided that the derivatives and expectations in (1) and and (2) exist. The inequality in (1) means that the difference $V - J^{-1}$ is a positive semidefinite matrix.

Assume now that the parameter θ is decomposed as $\theta = [\theta_\alpha^T, \theta_\beta^T]^T$ and the information matrix J is decomposed correspondingly into blocks

$$J = \left[\begin{array}{cc} J_{\alpha\alpha} & J_{\alpha\beta} \\ J_{\beta\alpha} & J_{\beta\beta} \end{array}\right].$$

It can be easily shown that the covariance of estimates of θ_β is lower bounded by the right-lower block of J^{-1}, i. e.

$$\mathrm{E}\left\{(g_\beta(x)-\theta_\beta)(g_\beta(x)-\theta_\beta)^T\right\} \geq [J_{\beta\beta} - J_{\beta\alpha}J_{\alpha\alpha}^{-1}J_{\alpha\beta}]^{-1}\,.$$

In the following the matrix $J_{\alpha\alpha} - J_{\beta\alpha} J_{\beta\beta}^{-1} J_{\alpha\beta}$ is called the marginal information matrix.

This matrix is studied for the following nonlinear filtering problem,

$$x_{n+1} = f_n(x_n, w_n) \tag{3}$$
$$z_n = h_n(x_n, v_n) \tag{4}$$

where x_n is the system state at time n, $\{z_n\}$ is the measurement process, $\{w_n\}$ and $\{v_n\}$ are two independent white processes (i. e. sequencies of mutually independent random variables or vectors), and f_n and h_n are (in general) nonlinear functions. The functions f_n and h_n may depend on time, n. Further assume that the initial state x_0 has a known probability density function $p(x_0)$.

Equations (3) and (4) together with $p(x_0)$ determine unambiguously the joint probability distribution of $X_n = (x_0, \ldots, x_n)$ and $Z_n = (z_0, \ldots, z_n)$.

Let $J(X_n)$ be the $(nr \times nr)$ information matrix of X_n derived from the above distribution. The problem that is solved in the paper is the computation the marginal information matrix for estimating x_n, denoted J_n, which is given as the inverse of the $(r \times r)$ right-lower block of $[J(X_n)]^{-1}$. The matrix J_n^{-1} provides a lower bound on the mean square error of estimating x_n. The computation is performed recursively, using the conditional probability densities $p(x_{n+1}|x_n)$ and $p(z_n|x_n)$, which follow from the equations (3) and (4).

5 Department of Econometrics

Head of Department:

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Secretary:

Eva Dostálová	–	Phone: (+42-2) 688 3029 e mail: eo@utia.cas.cz

Research Fellows:

Martin Černý	–	Decision processes e-mail: cerny@mbox.fsv
Alexis Derviz	–	Stochastic differential systems e-mail: Derviz@utia.cas.cz
Hana Havlová	–	Statistical analysis of a true random generator
Vlasta Kaňková	–	Stochastic programming. e-mail: kankova@utia.cas.cz
Jan Klacek	–	Macroeconomic analysis, financial economics
Jan Kodera	–	Nonlinear economic systems e-mail: kodera@nb.vse.cz
Milan Mareš	–	Fuzzy sets theory, decision-making theory. e-mail: mares@utia.cas.cz
Radko Mesiar	–	Fuzzy sets theory, triangular norm theory. e-mail: mesiar@cvt.stuba.sk
Vilém Novák	–	Fuzzy set theory, fuzzy reasoning models. e-mail: novak@osu.cz

Karel Sladký	–	Stochastic systems, dynamic programming, large-scale systems control. e-mail: sladky@utia.cas.cz
Andrea Stupňanová	–	Fuzzy sets theory, triangular norm theory.
Jan Špitálský	–	Econometrics e-mail: Spitalsky@utia.cas.cz
Zdeněk Tůma	–	Macroeconomics, macroeconometrics e-mail: Z.Tuma@patria.cz
František Včelař	–	Generalized choice model and Arrow problem in many–valued logical environment.

The Department concentrates on research in the following areas:

- stochastic analysis of economic systems and econometrics modelling,
- uncertainty processing in expert systems,
- stochastic programming,
- stochastic differential equations with application to capital markets.

Grants and Projects:

- V. Kaňková: *Sensitivity analysis, Approximations and Empirical Estimates in Multistage Stochastic Programming* (Grant GA AV No. A 1075502)

- M. Mareš: *Homogenous Classes of Vague Data.*
  (Grant GA AV No. A 1075503)

- M. Mareš: *Fuzzy Set Theoretical Models of Cooperative Behaviour of Econommic Subject.*
  (Grant GA ČR No. 402/96/0414)

- M. Mareš: *Information Asymetries on Capital Markets Emerging in Transition Countries, The Case of the Czech Capital Market*
  (Partner for the Czech Republic Phare ACE 1995, No.P95–214 – R, Coordinator M. Vošvrda)

- K. Sladký: *Time Dependent Stochastic Systems*.
  (Grant GA AV No. A 2075506)

- K. Sladký: *Complex Economic Systems and Decision Making under Uncertainty*.
  (Grant GA ČR No. 402/96/0420)

University Courses:

- *Faculty of Finance, University of Economics, Prague*
  - J. Kodera - Capital Markets
- *Faculty of Social Sciences of the Charles University:*
  - M. Mareš - Game Theory and Capital Markets
  - Z. Tůma - Macroeconomics I
  - F. Včelař - Probability Theory
  - M. Vošvrda - Probability Theory and Mathematical Statistics
  - M. Vošvrda - Econometrics

- M. Vošvrda - Capital Markets

- *Centrum for Economic Research and Graduate Education:*
  - Alexis Derviz - Econometrics
  - Jan Špitálský - Econometrics

- *Faculty of Electrical Engineering of the Czech Technical University:*
  - M. Mareš - Coalition game theory

Our Visitors:

- Prof. Nico van Dijk (University of Amsterdam)
- Prof. Didier Dubois (Universite de Toulouse)
- Dr. Igor Chernenko (Institute of System Analysis, Kijev)

Conference Participation:

- GAMM International Conference, Prague 1996, (Kaňková, Sladký)
- GAMM/IFIP–Workshop and Tutorial on Stochastic Optimization: Numerical Methods and Technical Applications,
  Neubiberg/Munich (Germany) 1996, (Kaňková)
- 2nd ERCIM Workshop Systems and Controls, Prague 1996, (Kaňková)
- 3rd International Conference on Distributions with Given Marginals and Moment Problems,
  Prague 1996, (Kaňková)

- Symposium on Operations Research 1996, Braunschweig, SRN 1996, (Sladký))
- Mathematical Methods in Economics, Prague 1996, (Kaňková, Sladký)
- Kvantitatívne Metódy v Ekonomike (Viackriteriálna Optimalizácia VIII, Bratislava 1996, (Kaňková, Sladký)
- IPMU '96 (Information Processind and Management of Uncertainty), Granada 1. - 5.7. 1996 (M. Mareš, R. Mesiar - Chairman of one section, Novák, A. Stupňanová)
- Ekonometrický den, Praha 1996, (Kaňková, Sladký, Vošvrda)

Members of the Department participated in joint research with their collegues from the University of Amsterdam, University of Cambridge and Humboldt University of Berlin.

Two members of the Department were promoted fellows of the Czech Econometric Society.
At present, M. Vošvrda is PastPresident, J.Špitálský is Treasurer.
M. Vošvrda and E. Dostálová are editors of theBulletin of the Czech Econometrics Society.
M. Mareš is Tresaurer of the Czech Society for Cybernetics and Informatics and member of American Mathematical Society.
K. Sladký is Managing Editor of Journal Kybernetika
M. Vošvrda is an elected member of the Grant Agency of the Czech Republic and chairman of its economic sciences division.

5.1 Vague and Verbal Quantities

The investigation of vague quantitative data modelled by fuzzy quantities, carried on during the last years, has continued. The previous approach to that problem, focused on the algebraic properties and on the relation to triangular norms, was significantly generalized. The recent development of the classical fuzzy numbers theory has shown its limits consisting in the disproportion between the rich class of formal fuzzy quantities and the relatively poor set of vague (usually verbal) expressions in the everyday life.

It becomes evident that each vague verbal quantitative expression represents a quite large class of fuzzy quantities having in some sense "similar" structure. The similarity may be connected with the generation of the vague data by the same source or with the similar "common" meaning of verbal expressions characterizing the vagueness of the quantities (e.g., "approximately", "rather more than ...", etc.).

In 1996 a model of the generation of vague quantities was proposed, and its basic properties were formulated. It defines the process of the generation of any particular fuzzy quantity as a superposition of two components. The first one is the *generating function* defined as an increasing real - valued function f which characterizes the structure of uncertainty typical for a source of fuzzy data. The second component is the *shape generator*, a piece–wise monotonous mapping ϕ, which describes the "normalized" shape of the fuzzy membership functions and can be interpreted as the representation of the verbal expressions describing the form of the modelled vagueness.

If two or more vague data are arithmetically processed due to some algorithm then this processing can be transformed to the analogous processing of the generating functions and shape generators. Meanwhile the operations with the sources (generating functions) are of arithmetical type, the combinations of the normalized memberships (shape generators) are mostly logical. The described model is exactly formulated in [136] [133] where its fundamental properties are derived and discussed, as well.

5.2 Dynamic Economic Systems under Uncertainty

The simplest way how to handle dynamic models where some uncertainties can occur is to assume only interval uncertainty in the coefficients of the model. However, more sophisticated approaches e.g. multistage stochastic programming, Markov reward models are also very useful since they well correspond to many real life-situations where some uncertainty occurs in the models that develop in time. Such models can be investigated over finite or infinite time horizon in discrete- or continuous-time setting.

An approach based on interval uncertainties was employed for the analysis of dynamic macroeconomic models. In particular, we focused our attention on the Keynes and neoclassical systems, as well as on the Walras–Keynes–Phillips model and showed how the interval uncertainties arising in the respective adjustment equations can influence the adjustment mechanism and stability margins of the macroeconomic equilibrium [189]. Similar methods were also used for the analysis of (local) stability of Walrasian general equilibrium model under uncertainties arising in the demand functions. In particular, on linearizing the set of the respective (nonlinear) differential equations around the equilibrium point, we assume that (due to uncertainties arising in the demand functions) coefficients in the resulting linear differential equation are known only to the extent that each belongs to a specified closed interval. We present some sufficient stability conditions for the resulting linear systems that guarantee also stability (along with stability margins) of the considered Walrasian equilibrium model [188].

A systematic attention was also paid to the models of stochastic dynamic programming and Markov reward models, in particular, to the *generalized dynamic reward structures*, in which the *transition probability* is generalized to an arbitrary *matrix with nonnegative elements* and in the continuous-time setting the *transition* *rate matrix* is generalized to an arbitrary *matrix with nonnegative off-diagonal elements* (a natural application of these models of substantial practical interest are the so-called *input-output models in economic analysis*). In this direction we investigated extensions of the classical technique of uniformization (or randomization) for bounded continuous-time Markov chains to continuous-time dynamic systems with generators given by arbitrary reducible matrices with nonnegative off-diagonal entries. The obtained results are of computational and theoretical interest. Some specific applications (for example input-output models in economic analysis) are discussed in detail to illustrate the conditions and the results.

Multistage stochastic programming problems cover an essential part of the above mentioned problems in the case of a finite time horizon. A complete knowledge of the actual probability measure is the necessary condition for the existence of an exact solution of the stochastic programming problems. In applications this assumption is only seldom fulfilled only seldom. Consequently, experience must be very often employed to obtain some information on the unknown probability measure. An approximate solution and some stability results were achieved in the moment approach to the stochastic optimization problems. Furthermore, the multifunctions connected with the multistage stochastic programming was investigated. The case of contaminated measure and interval estimates were investigated in [90], [88].

Of course, the intermediate relationship in an economic "system" determines a special form of the multistage stochastic programming problems. The aim of the paper [94] is to construct some of them. This approach was applied to an analysis of the problem of unemployment.

5.3 Stochastic Economics

A. Derviz' main research outcome in 1996 was a model of financial asset pricing under uncertainty, based on the adjoint stochastic differential equation following from the maximium principle for a representative investor. The model operates with the so called *shadow* asset prices and uses general equilibrium principles for the subsequent derivation of the Itô dynamics of nominal prices with which the assets are being traded in continuous time. The theoretic foundation of the model is a definition of the *adjoint* process for the stochastic optimal control problem, obtained synthetically from several special cases known from the control of diffusions literature. The resulting formulation makes it possible to address with the adjoint equation technique the problems where utility functions are state-dependent and non-zero portfolio adjustment costs exist [21]. An immediate application is a revised view of the traditional CCAPM (Consumption-based Capital Asset Pricing Model) approach to asset valuation, as well as a new characterization of bubbles in financial markets. Further application is expected in the models of credibility of monetary and exchange rate policies.

5.4 A Bivariate Integral Control Mechanism Model of Household Consumption

On the basis of nonstochastic steady-state relationships implied by the corresponding economic theory, stochastic disequilibrium relationships among relevant variables can be developed which will in steady-state simplify to the nonstochastic steady-state relationships. Based on this methodology and using, proceeding from properties of cointegrated variables, a theoretic model of household consumption, applicable to the existing Czech data, was derived. This extension of an Error Correction Mechanism model and of an Integral Control Mechanism model presents the household consumption in the form of a Bivariate Integral Control Mechanism model. In this model, the household wealth as a determinant of household consumption is simultaneously replaced by two integral variables, liquidity holdings and savings. Based on the model, short- and long- run consumption predictions as well as the equilibrium relations between consumption, liquidity holdings, savings, and disposable income can be assessed.

5.5 Econometric Model

An econometric model of the Czech Economy was finished [230]. There are two versions, the first version using statistical methods as the ARIMA approach, and the second version using methods from the disequilibrium model [232]. The main problem in application of the first version of the econometric model is embedding in historical data files. These files are too short for implementing statistical methods. From this point of view the second version is better to use. A measure of an economic efficiency through a price ergodicity was introduced to cover a variety of a market structures in both deterministic and stochastic framework. The evaluation of both upper and lower boundaries of inflation and an expectations-augment Phillips curve was estimated by linear regression. It was shown that standard economies have a known shape of an expectations-augement Phillips curve. Moreover, it was also shown that economies with an elastic price level but a very poor stabilization power of economy have an opposite slope of an expectations-augment Phillips curve. From the slope of the regression line between an inflation level and deviations of the output from the potential output, it can be argued on a position of economy from a point of view an efficiency of a market structure as a criteria of market economy [233].

6 Department of Pattern Recognition

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Research Fellows:

L. Bakule	-	Decentralized control of large scale systems e-mail: bakule@utia.cas.cz
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M. Haindl	-	Hypermedia, spatial data reconstruction and modelling e-mail: haindl@utia.cas.cz
P. Kolář	-	Complexity engineering e-mail: kolar@utia.cas.cz
J. Novovičová	-	Statistical approach to pattern recognition: feature selection and classification methods and criteria e-mail: novovic@utia.cas.cz

Postgraduate Students:

J. M. Rossell	-	Applied Mathematics (Spain)
P. Somol	-	Statistical Pattern Recognition
J. Vejvalková	-	Probabilistic Expert Systems
R. Vrňata	-	Statistical Feature Selection
P. Žid	-	Image Segmentation

Grants and Projects

- J. Novovičová, “Simultaneous feature selection and classifier design in statistical pattern recognition”
  Grant Agency of the Academy of Sciences of the Czech Republic; No. A2075608

- P. Pudil, “Multidisciplinary approaches to support of decision-making in economics and management”
  Grant of the Ministry of Education (jointly with the Faculty of Management, University of South Bohemia); No. VS96063

- M. Haindl, “VIRTUOUS - Autonomous Acquisition of Virtual Reality Models from Real World Scenes”
  European Union project INCO Copernicus No. 960174

PhD Projects:

- UPC Barcelona, Spain
  Rosell J.- M.: “Decentralized control using overlapping”
  Supervisor: L. Bakule

- Faculty of Mathematics, Charles University
  Somol P.: “Algorithms and Program Implementation for Solving Problems of High Dimensionality of Input Data in Statistical Pattern Recognition”
  Supervisor: P. Pudil

- Faculty of Nuclear and Physical Engineering, Czech Tech. University
  Vejvalkovă J. : "Integration of Expert Knowledge in the Probabilistic Expert Systems"
  Supervisor: J. Grim

- Faculty of Mechatronics, Technical University, Liberec
  Vrňata R.: “Knowledge-based System for Solving Feature Selection Problems in Statistical Pattern Recognition”
  Supervisor: P. Pudil

- Faculty of Mathematics, Charles University
  Žid P.: “Image Segmentation in Virtual Reality Acquisition Applications”
  Supervisor: M. Haindl

MSc Diploma Projects:

- Faculty of Pedagogy of the South Bohemia University at České Budějovice
  M. Brabec: “Neural Networks for Prediction of Binary Time Series”
  Supervisor: P. Kolář

- Faculty of Pedagogy of the South Bohemia University at České Budějovice
  V. Hryzbil: “Computer Based Analysis and Decomposition of Automata”
  Supervisor: P. Kolář

University Courses:

- UPC, Barcelona, Spain
  L. Bakule: "Control avanzado de sistemas"

- Faculty of Electrical Engineering, Czech Technical University
  M. Haindl: "Computer Vision"

- Faculty of Management, University of South Bohemia
  P. Pudil: "Statistics for management"
  P. Pudil: "Applied artificial intelligence for management"

- Faculty of Transportation, Czech Technical University
  J. Novovičová: "Mathematical Statistics"
  J. Novovičová: "Probability and Mathematical Statistics" (graduate)

- Faculty of Pedagogy of the South Bohemia University at České Budějovice
  Pavel Kolář: "Automata Theory"
  Pavel Kolář: "Theory of Formal Languages"
  Pavel Kolář: "Theoretical Backgrounds of Computer Science"
  Pavel Kolář: "Finance and Risk Management"

International Co-operation:

- Long-term guests:
  M. Schlesinger - Glushkov Institute of Cybernetics, Kiev, Ukraine

- Long-term visits:
  L. Bakule — UPV Bilbao, Spain;

- Representation in international bodies:
  M. Haindl — Governing Board member of the IAPR
  M. Haindl — Chairman of the IAPR Publication and Publicity Committee
  M. Haindl — member of the ERCIM - Editorial Board
  P. Pudil — Chairman of the IAPR Technical Commitee

“Statistical Techniques in Pattern Recognition”
P. Pudil — External PhD examiner for Cambridge University

- Co-operation on multimedia research:
  M. Haindl — Centre for Mathematics and Computer Science, Amsterdam, The Netherlands.[-5mm]

- Co-operation on statistical approach to pattern recognition:
  P. Pudil, J. Novovičová — University Surrey, GB; University of Valencia, Spain
  P. Pudil — University of Cambridge, GB

- Co-operation on the Euro-network project with
  – University Salford, GB – Dept. of Math. and Comp. Sci.
  – Universite Catholique de Louvain, Belgium – Center for Operations Research and Econometrics

- Co-operation on robust decentralized control design:
  L.Bakule — UPC, Barcelona, Spain

Conferences

The research results have been presented at several international conferences including:

- *1st European Conference on Structural Control*
  Barcelona, Spain, 1996
  (Proceedings will appear in World Scientific)

- *13th International Conference on Pattern Recognition*
  Vienna, 25 – 29 September, 1996, cf. [39].

- *Third European Congress on System Science*
  Roma, Italy, 1 – 4 Oktober, 1996, cf. [36].
- *International Archives of Photogrammetry and Remote Sensing XVIII Congress ISPRS*
  Vienna, Austria, 1996, cf. [53].
- *5th International Workshop on Data Analysis in Astronomy*
  (Proceedings will appear in World Scientific)
  Erice, Italy, October 27 - November 3, 1996.
- *AISB'96 Workshop and Tutorial Programme on Intelligent Feature Selection: Statistical and Neural Approaches*.
  Brighton, UK, 1996, cf. [175].
- *2nd European IEEE Workshop CMP'96 on Computer Intensive Methods in Control and Signal Processing*.
  Prague, Czech Republic, 1996, cf. [162].
- *Interdisciplinary Information Management Talks IDIMT'96*
  Zadov, Czech Republic, 1996, cf. [176].

Research Results

The scope of the Department of Pattern Recognition activities covers pattern recognition, with emphasis on statistical feature selection, probabilistic neural networks, modelling of random fields for scene interpretation and applications in economics and medicine. In all these areas the group members enjoy an international reputation expressed by scientific awards and memberships in governing bodies of international organizations.

Simultaneously research on robust decentralized control of large-scale systems has successfully continued.

6.1 Maximum-Likelihood Design of Probabilistic Neural Networks

The concept of probabilistic neural networks is based on approximation of class-conditional probability density functions by finite mixtures in the framework of statistical decision-making. The approach is related to radial basis function (RBF) neural networks and provides theoretically well justified means for a sequential maximum-likelihood design of layered neural networks.

At each level the class-conditional densities are approximated by finite mixtures with components from a common set of probability density functions. Thus the component density functions (RBF's) corresponding to neurons may be shared by all class-conditional mixtures without any structural limitations. The *shared components* naturally define an additional "descriptive" decision problem which can be identified in unsupervised way by maximizing the corresponding log-likelihood function (cf. Grim [39]). The descriptive classes may characterize e.g. some elementary situations or hypotheses. Numerically the problem can be solved by means of EM algorithm.

The parameters of descriptive components can be used to define *information preserving transforms* between consecutive layers. It has been shown that the statistical decision information is preserved both for the original- and descriptive decision problem and, simultaneously, the entropy of the transformed space is minimized (cf. Grim [36], Vajda and Grim [212], [211]). For this reason the transform may be expected to reduce the complexity of the underlying decision problem and simplify the statistical decision-making. The optimization procedure starting with unsupervised estimation of the descriptive distribution mixture and including transformation of the descriptive decision problem can be applied repeatedly to design multilayer networks. Only the estimation of class-conditional component weights at the highest level has to be supervised.

6.2 Multimedia Synchronization and Authoring

A new hierarchical synchronization model for the description of the time relations and regimes necessary for the presentation of multimedia or animated data which have either natural or implied time dependencies was developed [48]. The model generalizes some previous multimedia synchronization models by unifying time and event based synchronization concepts and offering a consistent framework in which to handle dynamic media presentation functionality.

The model represents major extension and generalization of the previously published multimedia synchronization models. While the model is able to cover all of their functionalities it handles also some new ones like the event based synchronization, incomplete timing, hierarchical synchronization, presentation time prediction, etc.

6.3 Spatial Data Reconstruction

Three new multidimensional data reconstruction algorithms were published in [53], [52]. These methods do not assume any knowledge of reconstructed data, they use available information from failed data elements surrounding due to spectral and spatial correlation in the multidimensional data space.

The methods are fully adaptive, numerically robust but still with moderate computational complexity. Experimental results on artificially removed data reconstruction show superiority of these methods over previously published ones.

6.4 Robust Decentralized Control of Large-Scale Systems

A new problem of decentralized state feedback control design for uncertain interconnected systems with time-varying delays in controls has been solved for nonlinear but nominally linear systems with unknown but bounded, possibly fast time-varying, parameter uncertainties. Only the bounds are supposed to be a-priori known. The problem considers only mismatched uncertainties. It means that the subsystems and interconnection uncertainties do not allow the entrance via the input matrix. The case of matched uncertainties has not been considered here because these uncertainties can be relatively simply avoided by using the high gain approach. The mismatched case has been selected in this case as a more general one. The Riccati equation approach has been adopted in this case. It means that the decomposition of parameter uncertainties into a sum of rank-1 matrices has been performed. The closed-loop system stabilizability condition has been proved using Lyapunov functions and inequality relations between products of matrices within a given disjoint-type subsystem-interconnection structure of the system. The solution of this problem does not appear in the literature, though it has various applications. The considered problem supposes uncertainties in delayed controls only. This formulation has been motivated by the improvements of the solution of certain class up to now not satisfactorily solved problems arising in structural control design of mechanical systems, particularly the problem of sensors delays of signal transmissions in the feedback loop which strongly influences the closed-loop system stability. A sufficient condition for decentralized stabilization using the Riccati equation approach together with simple conditions of solvability of the corresponding algebraic Riccati equation have been proved. The solution of the overall system is performed at the subsystems level only. No overall closed-loop system stability test is required. This aspect of solution reduces the control design complexity. The novel of this theoretical solution lies in the inclusion of uncertainties into decentralized delayed setting of the problem. Further, extensive numerical simulations have been performed on an example of a six-degree-freedom (DOF) building structure subjet to a horizontal ground acceleration, as an external disturbance. Each subsystem has its own actuator. Parameter uncertainties have been modelled as a difference between the given model resulting from experimental identification of a real world building and a well known model simplification approach based on a tridiagonal structure of stiffness and damping matrices. Simulation verification included also the eigenvalue analysis evaluation of such model simplification. The simulation results confirmed the expectations. It means that nondelayed sensors allowed higher gains of gain matrices together with faster movement of displacements. The centralized closed-loop system without any delay served as a reference case. The comparison has been made on system responses. The result (to be published) has been achieved in the cooperation with the University of the Basque Country in Spain under the support of the Basque Government.

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- S. Saic - 3D supercomputer modeling and visualization of rigid particles motion in viscous fluid (Grant Agency of the Czech Republic, No.102/96/0419 - jointly with Faculty of Science of Charles University)

- T. Suk - 3D shape reconstruction from intensity images (Grant Agency of the Czech Republic, No. 102/95/1378 – jointly with the Czech Technical University, Faculty of Electrical Engineering)

The research activity is focused on the following areas:

- theory of the invariants
- recognition of distorted images and patterns
- multisource and multitemporal data analysis
- image restoration
- applications in remote sensing, astronomy, medicine, archaeology, geodesy and geophysics

7.1 An Invariant Approach to Degraded Image Analysis

Analysis and interpretation of an image which was acquired by a real (i.e. non-ideal) imaging system is a key problem in many application areas such as remote sensing, astronomy and medicine. Since real imaging systems as well as imaging conditions are usually imperfect, an observed image represents only a degraded version of the original scene. Various kinds of degradations (geometric as well as radiometric) are introduced into the image during the acquisition by such factors as imaging geometry, lens aberration, wrong focus, motion of the scene, systematic and random sensor errors, etc.

In the general case, the relation between ideal image $f(x, y)$ and observed image $g(x, y)$ is described as $g = \mathcal{D}(f)$, where $\mathcal{D}$ is a degradation operator. In the case of a linear shift-invariant imaging system, $\mathcal{D}$ is realized as

$$g(\tau(x, y)) = (f * h)(x, y) + n(x, y),$$

where $h(x, y)$ is the point-spread function (PSF) of the system, $n(x, y)$ is an additive random noise, τ is a transform of spatial coordinates due to projective imaging geometry and $*$ denotes a

2-D convolution. Knowing the image $g(x,y)$, our objective is to analyze the scene on the image $f(x,y)$.

There are basically two different approaches to degraded image analysis: blind restoration and direct analysis.

Direct analysis of a degraded image is based on the following idea: in many cases, one does not need to know the whole original image, one only needs for instance to localize or recognize some objects on it (typical examples are matching of a template against a blurred aerial image or recognition of blurred characters). In such cases, only a knowledge of some representation of the objects is sufficient. However, such a representation should be independent of the imaging system and should really describe the original image, not the degraded one.

We derived two sets of the so-called *Blur Invariants* which are based on image moments in the spatial domain and tangent of the Fourier transform phase in the spectral domain, respectively. Their definition, proof of invariance and applications to the recognition of blurred portrait photographs can be found in [32], [34] and [33].

This work has been supported by the grant No.102/95/1295 of the Grant Agency of the Czech Republic.

7.2 3-D Supercomputer Modeling and Visualization of Rigid Particles Motion in Viscous Fluid

In both science and engineering, the problem of motion of small rigid particles suspended in viscous fluid are studied. One possible approach is the model of Jeffery in structural geology. Jefferys equations have been found only for some basic types of flow. Up to the present time, the most complex flow (general coaxial flow mixed with a simple shear) has not been solved. Numerical solution of the equations of Jeffery that enable modeling of evolution of multiparticle systems is time-consuming, and so is modeling of the flow around rotating particles. From the point of applications of the model of Jeffery, a suitable temporal visualization of patterns and structures appearing in the course of modeling is very important.

Evolution of a multiparticle system composed of non-interacting particles can be modeled by simultaneous solutions of corresponding Jefferyòs equations, and used to study of some natural phenomena, e.g. creation of preferred orientation of minerals in rocks. Software for modeling of multiparticle system evolution in general homogenous flow was developed and applied to study of origin of preferred orientation.

For applicability of the model of Jeffery, not only the motion of the rigid particle itself but also the motion of the surrounding fluid is very important. Some preliminary results of application of this approach were obtained in our geologically-oriented project, where an evolving porphyroblast (i.e. a specific mineral grain) was simulated as a rigid ellipsoidal particle growing and rotating in viscous flow, but only 2-D modeling was used. Computer implementation of a full 3- D model and a suitable temporal visualization have not been obtaineded yet and is planned for the future. A suitable temporal visualization of patterns and structures appearing in the course of modeling is very important. Since the time-consuming numerical procedure is executed separately on a supercomputer, the project requires to find a suitable form of interactive visualization of stored results on a graphic terminal. The first version of a user interface for modeling and visualization has been developed.

This research has been done jointly with Faculty of Science of Charles University and supported by the grant No.102/96/0419 of the Grant Agency of the Czech Republic.

7.3 Probability Distribution for Exact Nonlinear Estimation

Nonlinear Bayesian estimation has been studied. This research represents a generalization of the previous work [192], [193]. Exact computation of a posterior probability distribution is proposed even when the original nonlinear statistical model was linearized. A prior knowledge of the error of linearization is considered to estimate a posterior probability distribution of the estimated parameters properly. A special probability distribution of the measurements is designed by means of solution of a functional equation.

With such a distribution the computation of the posterior probability distribution is almost as easy as in the linear and normal case. Mean value and variance of this distribution is simply computed to be the same as the sample mean and variance of the measurements. The designed distribution slightly differs from the normal distribution even when the linearization error is copmarable with the standard deviation of the measurements. Probability density functions of the both distributions are compared in Figure 1. The linearization error was chosen two times larger than the required standard deviation of the measurement. If the linearization error is smaller, the both density function would not be graphically distinguishable in this scale.

The resulting posterior distribution represents the real state of knowledge of the all uncertain quantities concerned: estimated parameters, measurements and linearization error. The suggested approach can be applied to a wide area of nonlinear estimation problems. Currently, application in cartography (geometric transformations of images and maps) is studied (see [194]).

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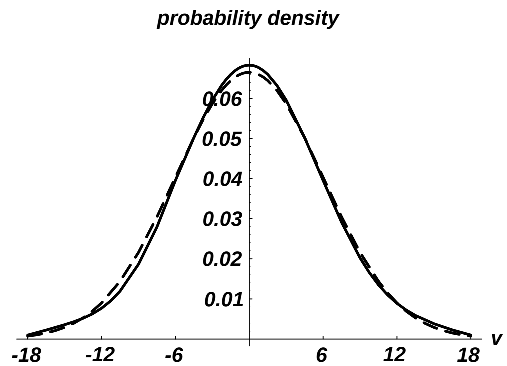

Figure 1: Comparison of the designed distribution (solid line) with normal distribution (dashed line)

7.4 Contextual Methods of Feature-based Classification

In the field of contextual classification, our activity is focused on the following partial goals of investigation.

- Multisource objects analysis using the context along temporal axis [102], [103].
- Local properties context.
- Optimal cobweb selection.
- Digital presentation of the obtained results and applications [101].

A method of local context analysis has been proposed which is based on the combined effect of autocorrelation and simple correlation. The method enables using both fast as well as flying window. The feature space created in this way gives a lot of information about stochastic relations inside the defined neighborhood or it can map the properties of the image point surroundings. The method has been applied to the images of magnetic domain structures from an optical microscope.

We propose to define the correlation function between two pixels of distance (u, v) by the relation

$$A(u,v) = \frac{\sum_{jk}\left(F_{jk} - \overline{F}\right)\left(F'_{jk} - \overline{F'}\right)}{\sqrt{\sum_{jk}(F_{jk} - \overline{F})^2 \sum_{jk}(F'_{jk} - \overline{F'})^2}} \,,$$

where the sums are defined over a rectangular image segment and F_{jk} is the gray value at pixel (j, k),F'_{jk} is the gray value at pixel $(j - u, k - v)$ and $\overline{F}, \overline{F'}$ are the corresponding mean values. We consider u only positive, v positive or negative. The computation can be performed directly on the original image.

Let us consider a set of translations (u, v) - i.e. an arbitrary cobweb S_r

$$S_r = \{(u_1, v_1), (u_2, v_2), ..., (u_r, v_r)\} \,.$$

To reduce the influence of the fact that we express in this way only linear dependencies, we must find optimal cobweb of translations. The construction depends on the size of window $m \times m$ and on what type of window, whether*fast or flying*, will be used.

We can very easily spread the system on the multispectral images. In this movement we can investigate spectral image structure, it means *a cube* window $m \times m \times z$ and combine the cobweb of selected translations from one sample with relations between the same or different places of the spectral channels.

To select an optimal cobweb of relations means obtaining the set of translations ordered according to their diminishing significance. We assume to have an arbitrary cobweb S_n of features

$f_1, \ldots f_n$. We propose to define the distance of classes ω_i, ω_k at feature f_j as

$$d_{ikj} = \{(\mu_{ji} - \mu_{jk})/(\sigma_{ji} + \sigma_{jk})\}^2$$

for every f_j .Then we compute the measure msr_j for R classes as

$$msr_j = \sum_{i=1}^{R-1} \sum_{k=2}^{R} d_{ikj}$$

and we select

$$f^\star = \max_j msr_j$$

as the most significant point of the cobweb. We define a matrix

$$B_{\max} = [b_{ik}]_{R \times R} = [d_{ik\star}]_{R \times R}$$

the elements of which are distances of classes of the selected feature $f^\star$. The next significant feature is selected according to the measure MSR_j defined by formula

$$MSR_j = \sum_{i=1}^{R-1} \sum_{k=2}^{R} (d_{ikj}/b_{ik})^2$$

for $j = 1, \ldots, N$ and the relation

$$f^{\bigotimes} = \max_j MSR_j.$$

In every step the matrix $B_{\max}$ is updated as follows

$$b_{ik} = \max(b_{ik}, d_{ik\bigotimes})$$

We continue in this way as long as a required number of cobweb points has been selected. The digital presentation of the achieved results using *Media Toolbook* is available.

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7.5 Applications in Archaeology: Classification and Measurement of Sherds

In the field of archaeology one of the most important objects are sherds (fragments of pots). When a new sherd is found, it needs to be measured, classified and archived. Until now archaeologists have classified sherds manually, which represents a great deal of routine work and takes much time (from 1/2 to 3 hours for each sherd). To cope with this fact, several projects of a computer aided classification of sherds have been introduced. In these projects, sherds are measured manually or semi-automatically with a help of a 3-D cursor. In our approach, we want to extend current methods to a system for an automated reconstruction of an archaeological pottery.

In the proposed process, a shape of a sherd is acquired automatically by a laser range finder. Sherds need to be oriented before the acquisition. This orientation is done manually in a computer assisted orientation process. After a range image of an oriented sherd has been acquired, profile and shape of the sherd are estimated. Next, the profiles of all sherds belong to a reconstructed pot are combined together to create a virtual profile of the pot. Based on this profile, the sherds are placed on appropriate positions on the pot. The hypotheses are generated by a computer and verified by archeologists. Finally, the reconstructed pot is visualized on a computer screen. Missing parts are also described for further completion.

The proposed method is based on the constraint on rotational symmetry of the original pots. Because the investigated pottery was made on a potter's wheel, this assumption is fulfilled. In addition, expert knowledge given by archaeologists are exploited whenever possible. Regarding that, the method should be robust and provide reasonable results.

Research in this area has been done in a cooperation with the

Computer Vision Laboratory at the Czech Technical University, Prague and the Department for Pattern Recognition and Image Processing at the Technical University, Vienna.

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