ACTIVITY REPORT '98

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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 concerned with the development of control, information and computer sciences including in particular system theory and random processes from the point of viev of mathematical modelling, decision making, automatic control and signal or data processing.

This report gives an overview of our research activities in 1998. 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.

Institute of Information Theory and Automation

Academy of Sciences of 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 Radiotechnics and Electronics and the Laboratory for Automation and Telemechanics. It means that in 1999 it remembers the 40th anniversary of its activities.

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 contaminated data processing, random fields and pattern recognition. Currently ÚTIA holds research grants from many domestic and foreign agencies.

The scientific library of ÚTIA contains more than 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. During 1996 – 1997 the Institute completely reconstructed and extended its local area network.

ÚTIA publishes the scientific journal Kybernetika which is registered by SCI and its impact factor is stabiliyed between 0,15 - 0,20. 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 on 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 essentially contributes to the activities of the Czech Society for Cybernetics and Informatics.

ÚTIA has developed close research and teaching contacts with many academic and industrial institutions. It is affiliated with several institutions of higher education, including the 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, Incs. 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. and continues in the extensions of the databases of other groups of prisoners.

The Institute organized the

- Prague Stochastics'98, Prague 1998 .

- 3rd IEEE Workshop on Computer Intensive Methods in Control and Signal Processing, Prague 1998.

and participated in the organisation of numerous other conferences.

Among others, the Institute is a coorganizer of

- Workshop on Conditional Independent-Structures and Graphical Models, helt in Toronto, Canada, in 1999.

Contents

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Grants and Projects:

- F. Matúš: Entropy functions and polymatroids.
  (Grant GA AV ČR No. A107 5801)

- J. Outrata: Non–smooth analysis in problems of continuum mechanics.
  (Grant GA AV ČR No. A107 5707)

- J. Pik: Discrete event theory application in development of dependable software.
  (Grant GA ČR No. 102/96/1671)

- 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: Conditional independence structures: Information-theoretical approach.
  (Grant GA ČR No. 201/98/0478)

University Courses:

- Faculty of Mathematics and Physics of the Charles University
  - Selected topics of optimization theory. (T. Roubíček)
  - Nonlinear partial differential equations and inequalities. (T. Roubíček)
  - Modern optimization theory. (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)
  - Bayesian networks. (R. Jiroušek)
  - Intelligent systems. (R. Jiroušek)
  - Logics. (J. Vejnarová)
  - Optimization methods. (J. Vomlel)

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

Our Visitors:

- Prof. Andreas Prohl (University of Kiel)
- Prof. Werner Schmidt (University of Greifswald)
- Dr. Andreas Ruffing (University of Munich).

Research:
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 Relaxed Variation Problems With Young Measures

A long-term program of relaxation of optimization problems by so-called generalized Young functionals, summarized together with some new results in [203], continues in various directions. Often, oscillation effects can be combined with concentration ones; in [151] we developed a relaxation theory as well as efficient numerical schemes for such sort of problems, using so-called DiPerna-Majda measures described explicitly in previous works. Optimization of systems governed by semilinear elliptic equations are investigated in [88] and [204]. The relaxation by generalized Young functionals was used to derive the maximum principle and to investigate existence of solutions of the original problems, and possibly the convexity of the relaxed problem which can be further used to derive sufficiency of the maximum principle or existence of Nash equilibria in noncooperative game situations. In [204] a system of semilinear elliptic equations is dealt with, while [88] investigates Navier-Stokes equations for incompressible viscous fluid. Besides, the evolution of microstructure connected with a martensitic phase transformation in metals, in particular in so-called shape memory alloys, was numerically studied in [228] in multidimensional vectorial cases. A numerical model describing behavior of ferromagnetic materials in external magnetic fields was analyzed in [129]. The paper [130] studies some invariance properties of quasiconvex functions which play a key role in the multidimensional vectorial calculus of variations.

1.2 Composition of Finite Distributions in Probability and Possibility Theories

When developing intelligent systems one has to represent and process knowledge of the area of interest. Naturally, there are many types of knowledge, some of which is very difficult to formalize. In our research we have concentrated to the knowledge that can be expressed as a multidimensional distribution of finite valued variables of both probabilistic and possibilistic character.

By *local*, or *partial* knowledge we understand the knowledge that can be represented by *low-dimensional* distributions, that is by distributions whose dimensionalities are not beyond the capabilities of human understanding. Naturally, an intelligent system has to represent a *global* knowledge of the field of application. Within the framework of our considerations it is represented by a multidimensional distribution whose dimensionality can reach hundreds or even thousands.

Having some marginal distributions we can get their extension in a unique way only when we introduce some type of (conditional) independence which is done by the following operators of composition.

Consider two (for the sake of simplicity) positive probability distributions $P_1\left((X_i)_{i\in K_1}\right)$ and $P_2\left((X_i)_{i\in K_2}\right)$. A *right composition* [95] of these two distributions is a probability distribution for variables from $(X_i)_{i\in K_1\cup K_2}$ defined by the formula

$$\begin{aligned} P_1\left((X_i)_{i\in K_1}\right) \triangleright P_2\left((X_i)_{i\in K_2}\right) &= \\ = P_1\left((X_i)_{i\in K_1}\right) P_2 &\left((X_i)_{i\in K_2\setminus K_1} | (X_i)_{i\in K_1\cap K_2}\right). \end{aligned}$$

Thus we are getting a probability distribution for which the variables $(X_i)_{i\in K_2\setminus K_1}$ are conditionally independent with variables $(X_i)_{i\in K_1\setminus K_2}$ given $(X_i)_{i\in K_1\cap K_2}$.

In the case of possibilistic distributions $P_1\left((X_i)_{i\in K_1}\right)$ and $P_2\left((X_i)_{i\in K_2}\right)$, the crucial question is how to define *conditional possibilistic distribution* $P_2\left((X_i)_{i\in K_2\setminus K_1} | (X_i)_{i\in K_1\cap K_2}\right)$. In accordance with [251] we can define it as a *T-residual*

$$P_2\left((X_i)_{i\in K_2}\right) \triangle_T P_2\left((X_i)_{i\in K_1\cap K_2}\right),$$

where T denotes a continuous t-norm.

Therefore, in analogy to probabilistic case, we define a *right composition of possibilistic distributions* by the expression

$$P_1\left((X_i)_{i\in K_1}\right) \triangleright P_2\left((X_i)_{i\in K_2}\right) = \\ = T\left(P_1\left((X_i)_{i\in K_1}\right), P_2\left((X_i)_{i\in K_2}\right) \triangle_T P_2\left((X_i)_{i\in K_1\cap K_2}\right)\right).$$

Generally, multidimensional distributions are composed from sequences of low-dimensional distributions by iterative application of operators of right composition

$$P_1 \triangleright P_2 \triangleright \ldots \triangleright P_n.$$

As each of the distributions P_i is defined for variables $(X_i)_{i\in K_i}$, the result of this computation is a distribution of variables $(X_i)_{i\in K_1\cup\ldots\cup K_n}$.

In [96] we showed that a Bayesian network can be represented by a sequence of low-dimensional probability distributions of very specific properties, so called perfect sequence. A sequence of distributions $P_1, P_2, \ldots, P_n$ is called *perfect* if the following equality holds for all $k = 2, \ldots, n$

$$(((P_1 \triangleright P_2) \triangleright \cdots \triangleright P_{k-1}) \triangleright P_k) = \\ = (P_k \triangleright (P_{k-1} \triangleright \cdots \triangleright (P_2 \triangleright P_1))).$$

Therefore, perfect sequences can serve as representatives of Bayesian networks also in possibility theory [252].

We believe that a wide class of graph models can be described by composition of probability distributions. Moreover, this approach opens new points of view to the whole area of graph modelling and provokes new question which have not been asked before.

1.3 Supervisor of Tertiary Control of Voltage and Reactive Power

The cause of relatively frequent failures of industrial control processes in practice lies in the fact that either part of the system or communication path between the center and a peripheral collapse. This way, control algorithms end up outside of their standard operational area. A supervisor of the system's state that is synthetized in form of an Mealy automaton takes care of the problem. The approach has been used for a concrete problem of voltage profile optimization and reactive power generation in power system of the Czech Republic. It can detect inconsistencies, store the previous state, alert service and recommend provisional control action.

The aim of the optimization is to cut down transmission losses. Unnecessary losses arise due to the fact that production of reactive power can often take place far from the locations where it is actually consumed. As a part of the paper [128], there is a discussion of possible partial tertiary control of U/Q when only a few of deployed secondary controllers are directly connected to the centre.

The essential feature of the realised approach is a possibility of an immediate transfer to manual control and permanent supervisory role of the dispatcher in charge during the whole process. That way, the dispatcher is continually offered the best trajectory in the state space that might be either accepted or rejected. Keeping the voltage profile within prescribed limits is of paramount importance for the security of the whole system. Overcharging shortens life expectancy of equipment while trespassing lower limits may lead to the voltage collapse and breakdown of the whole system.

The objective function is highly nonlinear and the problem even does not have a potential function i.e. the trajectory matters and action variables ranges are dependent on the position in the state space. Due to the strong interconnection of our grid with UCPTE, the excessive reactive power flows along the tie-lines are closely watched and penalized. The suggested optima are offered on a round o' clock basis. Each individual run lasts about 15 minutes on a Pentium P2, 450 MHz. During the time, the simulated annealing technique invokes 5000 times a procedure solving the system equations.

1.4 Conditional Problem for Joint Distributions on Finite Sets

The incentive comes from the field of decision making under uncertainty with probabilistic background. Different pieces of knowledge are integrated to form a unifying *joint distribution* representing a basis for subsequent decision-making.

The *marginal problem* consists in reconstruction of a joint distribution whose marginals equal to fixed small-dimensional distributions.

As a possible extension of the genuine marginal problem, the *conditional problem* is introduced where the resulting construct must comply with a set of prescribed conditional probabilities, [127]. It is necessary to distinguish between *objective* (Kolmogorov) probability and *subjective* (de Finetti) approach. In the latter, *coherence problem* incorporates both probabilities and conditional probabilities in a unified framework.

In the context of the former approach, it was shown that it is possible to split the task into solving the *marginal problem* independently and into subsequent solving pure *conditional problem* as a certain type of optimization.

First, an algorithm (Conditional problem) that generates a distribution whose conditional probabilities are equal to the given ones has been developed. The approach changes the starting joint distribution only to the extent necessary to reach the required equality on conditionals. Therefore, the final distribution inherits partially its internal structure from the original starting one. There are no problems with convergence and stopping rules, as the algorithm uses arithmetic of integers.

However, due to multimodality of the criterion function, the algorithm is only heuristical. It uses a certain gradient technique combined with an efficient parametrization (the so-called "invariant moves") of all fixed less-dimensional marginal distributions.

Second, a method has been suggested that unites *marginal* and *conditional problem* to a more general *consistency problem* for *objective probability*. Due to computational complexity, both algorithms are effective only for limited number of variables and conditionals e.g. 5 - 6 dichotomic random variables.

1.5 Optimal Design of Topology and Material of Mechanical Structures

We studied problems of so-called *Free Material Optimization* [150, 13] with additional technological constraints. Our goal was to find an optimum design of a material in a two- or three-dimensional continuum elastic body. The design variables are the *material properties* which may vary from point to point. Recently, we have analytically reduced the problem to a problem with only *one* design variable—the trace of the elasticity tensor. The discretized reduced problem leads to a convex mathematical program solved by interior-point algorithms [119, 43].

In the last year, we focused on problems with additional technological constraints, in particular on problems with multiple load cases. Here the goal is to design a structure/material which can withstand all the given loads, applied independently at different times, and which is still as light as possible. A conservative, "worst-case" approach to this problem leads to a nonconvex "min-max-max" optimization problem. We analyzed it, proved the existence of its solution and showed that it can be formulated as a semidefinite program and solved by available software [13].

Further, we analyzed so-called *Robust Optimum Design* problem. A robust structure is designed to be stiff not only with respect to the existing loads but also with respect to small random "incidental" forces. This problit, very important from the practical point of view, was again formulated as a semidefinite program of very large dimension. Instead of solving this program, we have proposed a so-called *cascading* technique, which enables to find a good approximation of the robust design by solving a "cascade" of problems of small dimension [149].

1.6 The Database of Ghetto Terezin

The development of the Terezin Ghetto database continued. Software for simultaneous updating and inserting new records off-line on several computers in different places, using different platforms was developed. All data were concentrated in the main database. The structure of the database was modified to reflect new demands and greater variability of processed data. It implied the necessity to re-program the tools for the database utilization. As historical research of this project part has been nearly finished, extensive checks were performed to reveal inconsistencies. Final formats for the German Memorial Book have been prepared and prints with all German transports were generated.

1.7 Mathematical Programs With Equilibrium Constraints (MPEC)

Under MPEC one understands optimization problems, where a parameter-dependent variational inequality (VI) or complementarity problem (CP) arises among the constraints. If the map, assigning the parameter the corresponding solutions of VI or CP is locally single-valued and Lipschitz, it is very convenient to couple the so-called implicit programming approach with a suitable bundle method of nonsmooth optimization. This technique is thoroughly investigated in [181], where one finds also a number of applications, mostly from shape optimization in continuum mechanics. If, however, the underlying equilibrium problems do not possess the above property, the situation becomes substantially more complicated. For this case we have developed a new approach based on the Morduchovich's generalized differential calculus for nonsmooth and set-valued maps. In particular, we have derived a verifiable condition, enabling to state workable optimality conditions and to construct a special nondifferentiable exact penalty function [179]. This penalty enables to solve numerically such difficult MPECs again via a suitable bundle code of nonsmooth optimization [180].

1.8 Block-Factor Fields of Bernoulli Shifts

Let $\eta = (\eta_i; \ ; i \geq 1)$ be an i.i.d. sequence, a Bernoulli shift, each η_i taking values in $\widehat{n} = 1, 2, \ldots n$, $n \geq 1$, with probabilities $p_1, \ldots, p_n$. Where $A = (a_{i,j}; \ ; 1 \leq i, j \leq n)$ is a matrix with entries in a finite nonempty set S, the infinite random array $(a_{\eta_i,\eta_j};\ ; i, j \geq 1)$ will be denoted by $A_{\eta,\eta}$ and called *block-factor field* of the Bernoulli shift η.

A random array $\zeta = (\zeta_{i,j};\ ; i, j \geq 1)$ with the state space S is *jointly exchangeable* if its distribution remains unchanged under permutations $(\zeta_{\pi(i),\pi(j)};\ ; i, j \geq 1)$ where π permutes positive integers. The array is *(jointly) dissociated* if its subarrays $(\zeta_{i,j};\ ; i, j \leq n)$ and $(\zeta_{i,j};\ ; i, j > n)$ are stochastically independent. Block-factor fields are obviously jointly exchangeable and dissociated. Let us say that a matrix A is *jointly reducible* if there exists $1 \leq k < l \leq n$ such that the k-th and l-th rows of A coincide, $a_{k,j} = a_{l,j}$, $j \in \widehat{n}$, and the k-th and l-th columns of A coincide $a_{i,k} = a_{i,l}$, $i \in \widehat{n}$. In the block-factor field $A_{\eta,\eta}$ every finite subfield $(a_{\eta_i,\eta_j};\ i, j \leq m)$ is jointly reducible a.s. once $m > n$; this is because in the sequence $\eta_1, \ldots, \eta_m$ one has $\eta_k = \eta_l$ for some $1 \leq k < l \leq m$, a.s.

In [160] we prove the following characterization of the block-factor fields. *A random array ζ has the same distribution as a block-factor field of a Bernoulli shift if and only if ζ is jointly exchangeable, dissociated and the subarrays $(\zeta_{i,j}; i, j \leq m)$ are jointly reducible a.s. for all sufficiently large m.*

Our methodology differs substantially from all approaches the field has seen before. Probabilities of configurations in these arrays are computed by combinatorial ideas motivated by the category theory. The used methods are mainly algebraic and rely on the structure of ring homomorphisms from rings of polynomials onto the underlying field.

1.9 Conditional Independence and Chain Graphs

The paper [224] gives the proof of a desired theoretical result concerning chain graph models for description of conditional independence structures. It confirms a completeness conjecture of S.L. Lauritzen and M. Frydenberg that, for every chain graph over N, there exists a discrete probability distribution over N which exhibits just those conditional independence statements which are enclosed in the chain graph. The contribution [222] gives an overview of recent results concerning chain graphs and several arguments in favor of their use. In particular, it gives a suitable interpretation of the factorization formula defining chain graph models.

In 1990, Frydenberg showed that every class of Markov equivalent chain graphs, that is chain graphs describing the same conditional independence structure contains a distinguished representative, called the *largest chain graph*. Paper [152] then contains a simple graphical characterization of those graphs which are the largest chain graphs together with a rapid algorithm which changes every chain graph into the corresponding largest chain graph. Moreover, a catalogue of all largest chain graphs over five variables is given.

2 Department of Control Theory

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General

The research in linear control theory has a long tradition at the Institute. In early 1960s, under the leadership of Professor Strejc, researchers at the Institute made significant developments in both transfer-function and state-space methods. During the 1970s and the 1980s members of the Department, lead by Professor Kučera, obtained significant results which launched an entirely new area of research worldwide. Among these is a parametrization of all controllers that stabilize a given plant (known as the Youla-Kučera parametrization) and the design of control systems via polynomial equations. In the 1990s, the research activities of the department range from robust control to nonlinear systems.

Application research in the Department concentrates on numerical methods for control system simulation and design. This results in various original software packages for control and simulation.

M. Šebek is the coordinator of EUROPOLY - The European Network of Excellence for Industrial Applications of Polynomial Methods. This large project is supported by European Commission. It is participated by thirteen European groups leading in the field of polynomial methods, namely ÚTIA Prague, CZ; University of Twente, NL; University of Strathclyde, UK; University of Glasgow, UK; Politecnico di Milano, I; LAAS CNRS, F; University of Uppsalla, S; Compureg Pilsen, CZ; Faculty of Technology Zlín, CZ; Slovak University of Technology, SK; ProCS Šala, SK; Czech Technical University, CZ; and University of Warsaw, P. The current list of EUROPOLY external members include Daimler-Chrysler, D; Duslo Šala, SK; Easy Control, CZ; Ericsson, S; PolyX, Ltd., CZ; ETH Zürich, CH; Johannes Kepler Universität Linz, A; and UMIST, UK. Interested European industries and research groups are welcome to join the Network. For info on numerous EUROPOLY activities, visit its Web site at `www.utia.cas.cz/europoly/` .

Activity of the Department in international technical and scientific societies is remarkable. Our members serve in governing bodies of the International Federation of Automatic Control (IFAC), of the Institute of Electrical and Electronic Engineers (IEEE) and of the International Federation of Information Processing (IFIP).

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. M. Šebek is an Associate Editor of the European Journal of Control.

Grants and Projects

- L. Baramov, Robust Nonlinear Control (The Japan Society for the Promotion of Science)
- S. Čelikovský, Nonlinear Systems: New Approaches to Control and Detection (Grant Agency of the Academy of Sciences of the Czech Republic)
- S. Čelikovský, (Czech–French project Barrande)
- J. Doležal, Prague Technology Center (Honeywell)
- V. Kučera, Robust Control Systems Design (Grant Agency of the Czech Republic)
- V. Kučera, Robustesse et structure des systemes lineaires sur anneaux (CNRS France)
- V. Kučera, Dynamic Control & Management Systems in Manufacturing Processes (European Community – Copernicus)
- V. Kučera, Advanced Methodologies and Tools for Manufacturing Systems (European Community – Copernicus)
- V. Kučera, Control Engineering and Research (Swiss National Science Foundation)

- M. Šebek, Industrial Applications of Polynomial Methods (Czech–Japanesse project)
- M. Šebek, Systems with Uncertainty and Constraints (Czech-French project – Barrande)
- M. Šebek, EUROPOLY – The European Network of Excellence for Industrial Applications of Polynomial Methods (European Community – Copernicus)
- M. Šebek, Analysis of Multidimensional Systems with Applications to Synthesis and Control (Czech–Italian project).

Teaching Activities

- S. Čelikovský, Modern Nonlinear Control, CINVESTAV unidad Guadalajara.
- V. Kučera, Faculty of Electrical Engineering, Czech Technical University, Prague: Algebraic Approach to Control System Design (graduate), Linear Systems (graduate).
- M. Šebek, Faculty of Electrical Engineering, Czech Technical University, Prague: Robust Control (graduate) and Algebraic Design Methods (postgraduate).
- M. Šebek, Belgian Graduate Course (together with H. Kwakernaak, NL).
- P. Zagalak, CINVESTAV del IPN, Mexico: Introduction to Control Systems (postgraduate).
- V. Kučera is a member of the Accreditation Board appointed by the Government and a member of the Scientific Boards of two universities (Czech Technical University, Prague and University of Western Bohemia, Pilsen) and three faculties (Faculty of Electrical

Engineering and Faculty of Mechanical Engineering, Prague and Faculty of Mechatronics, Liberec).

Invited Lectures

L. Baramov: Nonlinear Nonstandard H_∞ Control, Hokkaido Chapter of Society of Instrument and Control Engineers, Hokkaido University, Sapporo, Japan.

V. Kučera: Polynomial equations: A tool for control systems synthesis. Nantes, F.

V. Kučera: Three approaches to H_2 control theory. Uberlandia, BR.

V. Kučera: Robust regional pole placement: An affine approximation. Siena, I.

V. Kučera: Robust and optimal control via parametrization. Petropolis, BR.

V. Kučera: H_2 control theory: Comparison of approaches. Mexico City, MX.

V. Kučera: Linear systems: Algebraic approach. Mexico City, MX.

V. Kučera and M. Šebek: Robust control: Liberec, CZ.

M. Šebek: Numerical methods for polynomial matrices. University of Glasgow, UK and Tokyo Institute of Technology, J.

Our Visitors

- A. Bricaire, CINVESTAV del IPN, MEX,
- H. Kwakernaak, University of Twente, Enschede, NL
- G. Lebret, LAAS CNRS Tolouse, F
- F. Lewis, Univ. of Tex. at Arlington, USA
- M. Malabre, Inst de Recher. en Cybern. de Nantes, F
- L. A. M. Martínez, IRCYN, Nantes, F

- A. Roca Martinez, Univ. Polit. Valencia, I
- C. Moog, IRCYN, Nantes, F
- V. L. Morales, IRCYN, Nantes, F
- K. Ozçaldiran, Marm. Research Center, T
- A. Smirnov, CAISL, St. Petersburg, RU

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, Chairman of IFAC Technical Board and a member of IFAC Technical Committee on Linear Systems;
– 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 and of the Technical Committee on Control Design;
– Member of the Conference Editorial Board of the IEEE CSS;
– Executive Committee member of the Czechoslovakia IEEE Section;
– President of the Czech IEEE Control Systems Society Chapter.

Research

The current research objectives in the Department of Control Theory are in the analysis and design of control systems. Three main research directions are as follows:

- analysis and design of linear systems including robust control;
- numerical methods for control systems analysis and design including chaotic systems;
- analysis and design of nonlinear control systems.

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

2.1 Singular H_∞ Control of Linear and Nonlinear Plants

The research was focused on extending standard results on H_∞ control for both linear and nonlinear systems to cases when certain rank conditions fail. The approach is consistently based on the chain-scattering formalism and systems factorization which allow simple parametrization of a solution set (in the linear case the whole solution set). It is thus an extension of the well-known work of H. Kimura. Our original approach avoids using descriptor forms and/or infinite and imaginary-axis zeros compensators. For some cases where a proper chain representation of the plant does not exist, an elegant extension was proposed – the so-called *generalized chain representation*. These results were presented at the MTNS 1998 conference in Padova, Italy ([12] for the linear case, [11] for certain nonlinear cases). These papers were further selected for publication in the Proceedings. A related result was also accepted for presentation at the *7th IEEE Mediterranean Conf.,* Haifa, Israel.

Supported by the Grant Agency of the Czech Republic under contract 102/97/0861 and by the Ministry of Education of the Czech Republic under contract VS97/034.

2.2 Output Regulation of Nonlinear Systems with Nonstabilizable Linearization

The problem of output regulation of a class of the so-called singular triangular form systems with single input has been considered in [249]. The problem of output regulation consists in tracking reference signal and/or rejecting disturbance using static state feedback. Singular triangular forms has uncontrollable linearization and therefore may fail to be stabilizable in linear approximation. For that reason, it is not possible to the standard way. Moreover, smooth solution of the problem need not exist. In [249] construction of continuous feedback has been presented that solves the output regulation problem. Basic property of the studied class of triangular systems is so-called formal solvability of the well-known regulator equation. Numerous examples and case studies were presented as well.

Supported by the Grant Agency of the Czech Academy of Sciences, A 207 5702.

2.3 Pole Contours for Space-Time Systems

The space-time systems are described by variables which are not only evolving in time but are also distributed in space. Typical examples include pipelines, paper machines, cement furnaces and steel rolling mills. Some control problems for such systems are difficult to solve by individual PID controllers and they need a deeper analysis via transfer functions.

For infinitely long systems (i.e. for systems such long that the boundary effects can be neglected) the transfer functions are 2-D rational functions (two variables in the continuous domain: s - space derivative, p - time derivative, in the discrete domain: w - space shift, z - time shift). The polynomial approach, traditional in ÚTIA, can be used for analysis and synthesis of control. Two-D polynomial equations can solve such problems as pole assignment.

Something is different from the standard 1-D systems: poles and zeros are not individual points but contours in 2-D complex space. A method for drawing such contours was elaborated for stability analysis. During this work, a peculiar class of continuous systems was discovered: unstable systems whose response grows (in time) faster than exponentially. There are no such discrete systems. This phenomenon shows that the 2-D continuous sytems are not simply similar to the discrete ones.

Supported by the Grant Agency of the Czech Republic under contract 102/97/0861 and by the Ministry of Education of the Czech Republic under contract VS97/034.

2.4 Deadbeat Control as an LQ Regulation

Deadbeat control is a typical example of linear control strategies in discrete-time systems. It consists of driving each initial state of the system to zero in shortest time possible.

In contrast, the objective of linear–quadratic regulation is to find a linear state feedback which stabilizes the system and, for every initial state, minimizes the l_2 norm of the system output.

The deadbeat control has been shown to be a special case of the linear-quadratic regulation. This surprising result follows from the interpretation of the two design procedures, obtained in isolation and fundamentally different from each other, in terms of pole placement, a useful reference design problem.

The result is as follows [141]. Let

$$x_{k+1} = Fx_k + Gu_k, \quad k = 0, 1, \ldots$$

be a linear reachable system and let T be the similarity transformation that brings the system to the reachability standard form. Then the linear state feedback that minimizes the l_2 norm of

$$y_k = Tx_k, \quad k = 0, 1, \ldots$$

is a deadbeat control strategy.

The significance of the result is both didactic and practical. It provides further insight and alternative design procedures.

Supported by the Ministry of Education of the Czech Republic under contract VS97–034 and by the Grant Agency of the Czech Republic under contract 102/97/0861.

2.5 Transfer Function Equivalence

A study of equivalence, from the transfer function point of view, has been made for ten commonly used feedback and feedforward control system configurations [140]. Two controllers are called transfer–function equivalent if their application to the given system results in systems that have the same transfer function. It is shown that a cascade controller is transfer–function equivalent to a two–degree–of–freedom controller as well as to a static feedback applied to a dynamic extension of the system.

The subclasses of these controllers that are equivalent to a standard static or dynamic, state or output feedback have been identified. The proofs are constructive and provide simple design procedures.

Two transfer–function equivalent controllers can have different internal properties. That is why a complete stability analysis of the resulting systems has been carried out.

These results are important *per se* in linear system theory. They are also useful in applications. A typical application area is the model matching problem. The results presented allow splitting the problem in two linear subproblems: first a cascade compensator is determined to achieve the match and then realized in terms of the configuration desired.

Supported by the Grant Agency of the Czech Republic under contract 102/97/0861 and by the Ministry of Education of the Czech Republic under contract VS97–034.

2.6 Simultaneous Stabilization - Polynomial Approach Using LMI

Simultaneous stabilization of a family of single-input single-output plants by one fixed controller of a given order is known to be a very difficult problem. Using polynomial approach, it can be interpreted as an NP-hard Bilinear Matrix Inequality (BMI) feasibility problem. This BMI problem has been reformulated as an Linear Matrix Inequality (LMI) problem with an additional non-convex rank constraint for which two heuristic solution methods have been proposed. The first one hinges upon rank minimization by potential reduction while the second one is based geometric properties of the intersection of a set of elipsoids [72], [73].

The results were achieved in cooperation with LAAS CNRS, Toulouse, France under the Barrande project No. 97026.

2.7 Numerical Algorithms for Polynomial Matrices

Polynomial methods have been the major contribution of the institute to linear control. The methods are characterized by extensive use of polynomial matrix operations and equations. Their successful industrial application naturally relies on good numerical algorithms for polynomial matrices.

A new class of computational procedures - called the second generation - has been developed that is based on interpolation and Sylvester matrices. It currently includes solvers for various special polynomial matrix equations and first numerically stable procedures for triangularization, greatest divisors and rank evaluation of polynomial matrices [71, 70]. The second generation methods appear to be more efficient as well as more reliable than classical routines.

Quite recently, a break-through has been achieved leading to brand new group of methods - tentatively called the third generation - that is even more reliable and namely more efficient than the second generation. These methods employ sophisticated interpolation using discrete Fourier transform and enable to use Fast Fourier Transform (FFT) procedure. The first algorithms derived include determinant, rank and adjoint computation for a polynomial matrix and their performance is really extraordinary [82, 83].

Supported by the EC project CP97:7010 EUROPOLY.

2.8 The Trajectory Root Locus and Its Applications

The behaviour of constant linear dynamical systems was extended to behaviour of constant nonlinear dynamical systems using the complex plane C. This extension was applied to study nonlinear systems. The notion of trajectory root locus — the locus in C of local eigenvalues of system Jacobian matrix parameterized by the time t — was introduced and applied both for the analysis and synthesis of nonlinear systems, mainly of chaotic and hyperchaotic behaviour.

To be specific, consider three trajectory root loci of systems with escalated complexity.

Firstly, trajectory root locus of constant linear system $\dot{x} = Fx$ consists generically of the eigenvalues of its state matrix F.

Secondly, trajectory root locus of pendulum. At the equilibria the trajectory root locus has fixed points — the eigenvalues i, −i and 1, −1. Outside the equilibria, the trajectory root locus fills segments of the cross inside the equilibria; the homoclinic trajectory has the trajectory root locus filling completely the cross.

Thirdly, the trajectory root locus of SISO nineth order constant linear system with Lur'e static, smooth, odd, symmetric nonlinearity giving hyperchaotic behaviour. The system of the ninth order with one real eigenvalue, eight complex conjugate eigenvalues (poles), eight complex conjugate zeros and one real gain was designed in such a way to exhibit hyperchaotic behaviour. We know apriori that the trajectory root locus lies on the segments connecting the poles and zeros, the segments being parameterized by the slope of the nonlinearity. This was used to design the candidate of hyperchaotic behaviour. Some of the poles and zeros were designed to lay in C_+, some to lay in C_-. Due to this also the trajectory root locus parameterized by the slope of the non linearity changes its position in C_+ and C_- giving partly the expansion, partly the contraction, the attributes of chaos or hyperchaos, [1].

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3 Department of Adaptive Systems

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Year 1998 has been full of changes within Department staff.

First of all, it was "harvesting" year for PhD thesis. Dr. L. Berec submitted and successfully defended his thesis [16]. F. Kraffer submitted his thesis [120]; it was defended in Mid January 1999. H. Gao and J. Rojíček submitted them too [50, 199] and they are waiting for (hopefully positive) responses of reviewers.

L. Tesař, T. Guy, P. Ivanova, L. Jirsa and N. Khailova will submit them (hopefully again) soon. Thus it is not surprizing that a new generation of PhD students joined us (M. Králík, B. Kovář, A. Regner and S. Pěnička). It is also not surprizing that some people left us completely (P. Klán) or work with us part-time only (L. Berec, P. Ivanova, J. Rojíček). We wish them all good luck in life and science as well as to those who are with us for years or (re)joined us recently (I. Nagy, R. Matulík, M. Kadlecová, Ch. Vialatte, F. Kraffer).

Activities of the Institute include cybernetics, informatics as the fields dealing with analysis and design of systems generating predictions, making decisions or controlling other systems. Our Department inspects systems that have the added ability to modify their behaviour in correspondence with the changing environment or operating conditions. This essential feature enhances the efficiency of the systems performing the tasks listed above.

We have been active in this area for decades and have reached significant conceptual, theoretical, algorithmic, software and application results. Gradually, the Bayes-based theory of decision making under uncertainty has become fixed — and successful — methodological kernel of our work.

The interplay between theory and (always limited) computing power is the leitmotiv of our current research. This difficult problem is addressed from all possible directions:

- We learn what complexity means in reality by solving practical demanding problems in radiation protection, in transportation, in economic and technological systems, in signal processing, in nuclear medicine etc.
- We gradually improve our know-how in order to widen the applicability of "classic" adaptive systems to more and more complex situations.
- We inspect theoretically possible new approaches to the construction of adaptive systems.

This text describes our effort to widen applicability of theoretically justified adaptive systems. However, no report can fully reflect real contents of papers, seminars and discussions with partners in academic as well as applied sectors. Please, take this incomplete information as an invitation to meet us and to enjoy the creative and friendly atmosphere which we consider just as important as the formal results.

Grants and Projects

The results described in the following sections have been obtained thanks to the continued effort of the research team. Nevertheless, the achievements would be impossible without substantial support from many sources. The following list is meant as an acknowledgment.

- L. Bakule – *Robust decentralized control of large-scale systems* (GA AV ČR A2075802)
- H. Gao – *Bayesian approximate recursive identification and on-line adaptive control of Markov chains with high order and large state space* (GA ČR 102/98/P059)
- J. Kadlec, J. Schier – *A high speed logarithmic arithmetic unit* (Phase I Esprit 23544 successfully finished; Phase II Esprit 33544 starts from 1.1.99)
- J. Kadlec *INFRA-II No. LB98250: New library sources in the area of basic research*
- M. Kadlecová – *Ideallist-East, INCO-Copernicus network of excellence, working group 977122. "Information Dissemination and European Awareness Launch for the IT programme in East Europe"*
- M. Kárný – *Decision-support tool for complex industrial processes based on probabilistic data clustering* (Esprit 25729, Phase I, successfully finished)
- M. Kárný – *Adaptive dynamic elements and their connections for dynamic decision making under uncertainty* (GA AV ČR A2075606, successfully finished)
- M. Kárný (J. Mošna, ZČU, Plzeň) – *New approach to optimality and adaptivity of uncertain systems* (GA AV ČR A2147701)
- F. Kraffer – *Shell International Donation No. C9993079/00/021297 for a two month visit to the U.S.A. including presentation at the 36th IEEE CDC*

- F. Kraffer – *Fellowship at the Thematic Term on Linear Algebra & Applications to Control Theory, Centro Internacional de Matemática* (Fundação da Universidade de Lisboa)
- R. Kulhavý – *Global approximation of model in recursive Bayesian parameter estimation* (GA AV ČR A2075603, successfully finished)
- R. Kulhavý – *Qualitative and analytical model based fault detection for chemical processes* (Copernicus COP-94 01320, [FDI], successfully finished)
- P. Nedoma – *Enhancement of the EU decision support system Rodos and its customisation for use in Eastern Europe* (Copernicus PL963365, [Rodos])
- P. Nedoma – *Adaptive systems: theory, algorithms and software for practise* (GA ČR 102/97/0118)
- J. Schier – *PTT and OTT enhancement for the collision avoidance radar* (Dutch STW agency DEL 22.2733, [Poet], successfully finished)

University Courses

Education is an integral part of the research. This is reflected in the fact that we are supervising a relatively high number of MSc theses and undergraduate research projects. To attract the interest of students, the members of the Department give regular undergraduate courses:

- Faculty of Physical and Nuclear Engineering, Czech Technical University
  Adaptive Control (M. Kárný)
- Faculty of Electrical Engineering, Czech Technical University
  Estimation and Filtering Theory (R. Kulhavý)
  Selected Applications of Estimation Theory (R. Kulhavý)
  Adaptive methods for signal processing (J. Kadlec)

Parallel algorithms and architectures (J. Schier)

- Faculty of Transportation, Czech Technical University
Principles and Applications of Parallel Computation
(J. Kadlec)
Course of Probability Theory and Statistics (I. Nagy)
Software Tools for DSP Programming (J. Kadlec)
- Faculty of Chemical Technology, University of Pardubice
Automatic Control Theory (P. Klán)

International dimension in teaching has been reached through the departmental 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 West Bohemia.

We also serve as members of committees that judge submitted doctoral thesis. At international level, M. Kárný reviewed thesis of M. Žele, Slovenia, and L. Bakule acts as a PhD Defence Committee Member, UPC, Barcelona, Spain.

Conferences

We hosted several conferences including:

- International FDI Workshops at Mariánská, Krušné hory related to our FDI project.

We also organized now traditional

- 3rd European IEEE Workshop CMP'98 *Computer Intensive Methods in Control and Data Processing: Can we beat curse of dimensionality?* [198].
- 8th IFAC/IFIP/IMACS/IFORS Symposium on Large Scale Systems, Patras, Greece, 1998 (an invited session organized by L. Bakule).

Guests

- *Dr. E. L. Sutanto* (UK), *Dr. A. Quinn* (Ireland), *Dr. O. Wolkenhauer* (UK), *Dr. C. Cooper* (UK), *Dr. A. Flexer* (Austria), visited us in connection with Esprit project 25729.
- *Dr. T. Tagarev* (Bulgaria) has helped us much in non-linear data processing [229, 230].
- *Christian Vialatte and Emmanuelle Legrand* (UK) visited us in connection with Esprit project 33544.
- *Dr. M. Žele* visited us within the framework of bilateral cooperation with Slovenia in FDI area.

Travels and International Cooperation

Conference trips were mostly connected with successful presentations. Thanks to the support gained from various grants, PhD students were given opportunity to visit Oxford, Reading, Budapest, Beijing, Glasgow and Dublin. Coordination and working visits were mostly related to major European Community cooperation projects. The key activities are:

- L. Bakule
  long-term stay at UPC, Barcelona, Spain,
  cooperation with UPV, Bilbao, Spain, chair of a session and invited lecture, LSS'98, Patras, Greece,
  Member IFAC TC Large Scale Systems
- J. Böhm
  coordination of Predcon Project, Bratislava, SR,
  research within Predcon Project, Oxford, UK
- J. Bůcha
  lecture CONTROL'98, Swansea,
  lecture RIP 98, Kouty nad Desnou
- H. Gao
  lecture, IMACS Symposium Mathmod'97, Wien, Austria,

IFAC Symp. Safeprocess'97, Kingston U. Hull, UK,
research visit, Northeastern University, China

- P. Ivanova

lecture, International Workshop on Advanced Black-Box Techniques for Nonlinear Modelling, Katholieke Universiteit Leuven, Belgium

- L. Jirsa

study stay within Predcon project, Oxford, UK
presentation within Central European Partnering Days, Eureka, St.Poelten, Austria

- J. Kadlec

coordination of Esprit projects, University of Reading, University of Newcastle, UK,
workshop of COSY Theme 2 project, University Mulhouse, Mulhouse, France,
IEEE workshop SPS'98 Leuven, Belgium,
meeting of an Esprit project, Trinity College Dublin, IRL,
University Strathclyde, Glasgow, preparation of Phase II of HSLA Esprit project, Upsalla University, Sweden,
lecture, IFAC workshop v Glasgow Scotland UK,
defence of EU tender application ESIS lot 4 Czech Republic, EU ISPO office Brusseles, Belgium,
short study stay within an Esprit project, School of Electrical Engineering, Korea University, Prof. Tae-Woong Yoon Kimhua Technology, Seoul, South Korea,
coordination of Inco project Ideal-List-East and representation of Czech Republic with the CZ stand at IST98 exhibition, Wien, Austria (Start of the "Information Society Technology" section of the EU 5th framework programme)

- M. Kárný

meeting of an Esprit project, Trinity College Dublin, IRL,
lectures ACASP'98, Glasgow,

lecture CONTROL'98, Swansea

- F. Kraffer
  invited lecture, CINVESTAV–IPN, Mexico,
  lecture, 6th IEEE Med, Alghero, Sardinia, Italy,
  invited lecture, Centro Internac. de Matemática, Portugal
- R. Kulhavý
  lecture and organization of two invited sessions, International Symposium on Mathematical Theory of Networks and Systems, Padova, Italy
- P. Nedoma
  Rodos coordination meeting, Nuclear Power Plants Research, Trnava, Slovakia
- P. Pecha
  Rodos coordination meeting, Nuclear Power Plants Research, Trnava, Slovakia
- J. Rojíček
  research within Predcon project, Oxford, UK,
  research within Predcon project, Bratislava, SR
- J. Schier
  IEEE workshop SPS'98 Leuven, Belgium,
  research within HSLA Esprit project, Leuven, Belgium
- L. Tesař
  research within Esprit ProDaCTool project, Trinity College Dublin, IRL
- M. Valečková
  lecture IFAC Workshop Adaptive Systems in Control and Signal Processing, Glasgow, UK,
  study stay in SZTAKI, Budapest, Hungary,
  research within Predcon project, Oxford, UK

3.1 Clustering Improving Operator's Performance

A complex process (rolling mill, transportation system, computer supported medical diagnostic system etc.) offers to the operator a lot of data which should be used for an efficient maintenance of the process in question. The resulting performance depends heavily on the skills and mood of the operator. Thus it is desirable to provide an advisory system that drives him to high performance areas and warns him against probable system misbehaviour.

The solution we elaborated and is described in details in the technical annex appended to the final report of the ProDacTool project. It is based on the following idea: the differences in operation quality are believed to manifest themselves in different modes of the distribution of the observed data. This distribution is approximated by a mixture of unimodal distributions (components). Each component is qualified by the expected performance and the best one provides a basis for the advisory system: the operator is shown appropriate univariate cross-sections on it.

The efficiency of this approach has been demonstrated on simulated and real rolling mill data. Its success stems from our ability to efficiently perform mixture estimation in high dimensional spaces (say 50 000 records each containing 40 variables). It was achieved by a novel combination of and efficient Mean-Tracking (M-T) algorithms with quasi-Bayesian estimation of mixtures [108, 232].

The proposed algorithm also helps us to get an efficient low-dimensional parameterization of controlled Markov chains we are using in designing universal adaptive systems for predicting or controlling non-linear stochastic systems [245, 246].

3.2 Computer-Aided Design of Adaptive Controllers

Adaptive controllers optimizing quadratic criterion with the help of recursively identified linear models having Gaussian process noise (LQG) proved repeatedly their full scale applicability (for our recent experiments on a heat-exchange station see [23]). Their efficient implementation is, however, non-trivial. The ambitious project of their computer-aided design launched several years ago made a significant progress. At present, a MATLAB toolbox ABET98 [182], [26, 175] for a complete "batch" design is available. ABET98 functions can be used to prepare MATLAB program that converts user's knowledge, objectives and restrictions into a completely pre-tuned controller. A project of an interactive design of adaptive controllers, DESIGNER 2000, has been started as a natural continuation. The performed study [8] specified basic properties of DESIGNER 2000 and approved the feasibility of this project [6, 7].

The present advanced state has been reached by combining theoretical, algorithmic and software activities. Let us characterize them.

Incorporation of prior knowledge. The user's prior knowledge about the system to be controlled together with data from preliminary experiments are converted into a prior model characterizing unknown parameters involved. Experience with the relevant algorithm for the conversion is described in [175]. The algorithm weights the processed knowledge items so that a suitable compromise is found in spite of their imprecise, repetitive and contradictory nature. This:

- increases the chance to estimate a good model structure,
- serves for initiation of on-line estimation and
- provides an alternative model needed for the generalized forgetting which is used to make the adaptation robust.

A novel sequential stopping rule. A substantial part of evaluations performed in the discussed area relies on simulations. They should provide reliable estimates of inspected quantities. Thus they should rely on long runs. The simulation length decides on computational time which can easily become excessive. Thus a compromise is needed. This stimulated development of a sequential stopping rule that balances the gained precision and computational load. Such a rule has been proposed using a classical theory of sequential stopping on a universal model relying on ergodicity of the inspected process [197]. The rule is quite efficient and can be used for increasing efficiency of majority of simulation based evaluations.

Advances in the control design. General algorithm for LQ synthesis, which is based on input-output models has been further improved. It enables us to minimize a more general type of quadratic criterion [24]. In connection with it, properties of the input reference signal as an analogy to the output reference (set point) into the LQ optimization has been further studied [25].

Spline-based adaptive LQ hybrid controllers provide complement to the discrete-time controllers. They respect continuous-time evolution of the controlled system as well as the discrete-time nature of the controller. In comparison with the traditional solutions, they should reach higher control quality by filtering that reflects properties of involved signals [55, 238, 239].

Extensive testing of LQ adaptive controllers. Adaptive and non-adaptive LQ controllers have been implemented in an LQ toolbox for Matlab and Simulink. The implementation includes the original extensions like the discussed input reference or data-dependent penalizations.

Extensive tests performed with this toolbox and documented in [20, 21, 22] help the user:

- to share our long term experience with capabilities and limitations of the adaptive controllers,
- to tune controllers after their automatic pre-tuning [199],
- to exploit the novel features that extend the applicability of the controllers.

Object oriented design. New methods of object oriented design have begun to be used in the DESIGNER 2000 project. They are based on Unified Modeling Language. It supports the seamless integration of algorithmic, graphical user interface and knowledge oriented DESIGNER 2000 parts.

3.3 Robust Control of Multivariable Systems, Including Numerical Algorithms

A large class of engineering problems admits the simplest model — a finite-dimensional linear time-invariant system — where state space and frequency domain are the two main design methodologies. In control applications with vector-valued signals, classical polynomial methods of frequency domain generalize to multivariable methods based on polynomial matrices. The polynomial matrix methods, however, lag behind their state space counterparts in several aspects.

A polynomial matrix method for performance and stability robustness of multivariable control systems is described in [120]. It decreases the inherent conservatism of $\mathcal{H}_\infty$ design, increases stability robustness of $\mathcal{H}_2$ design, and guarantees a wide applicability by considering the most general control diagram – the standard structure set-up. Although the method relies on polynomial matrix operations, some fundamental results from quadratic optimization in state space were exploited in the analysis of the problem.

Principal reasons for the restricted applicability of polynomial matrix methods are numerical unreliability and inability to compute system-theoretically relevant solutions to various polynomial matrix operations like linear and quadratic equations. Publications [121, 122, 124, 125], and [123] pioneer the use of geometric-type techniques in the computation of polynomial matrix operations. Advantages over existing methods are avoidance of elementary polynomial operations in computation, application of ideas found in numerical analysis literature, and level of abstraction just high enough – although higher than in the mainstream literature – to separate structural questions from computation.

F. Kraffer received the Josef Hlávka Award 1998 as an acknowledgment of these results.

3.4 Robust Decentralized Control of Large-Scale Systems

A new extension of the Inclusion Principle has been achieved for linear dynamic systems. The results are based on a general structure characterization of complementary matrices involved in the input-state-output Inclusion Principle.

Aggregations and restrictions are adopted as two practically important classes within the derived scheme. Further, contractability conditions for feedback controllers have been presented including decentralized control design. The identified structure enables the formulation of explicit conditions on the complementary matrices that are significantly easier than the conditions considered up to now. Moreover, the derived conditions enable much more flexible choice of complementary matrices both for analysis and synthesis of control problems. Further, this new extension of the Inclusion Principle has been adopted on the LQ control design by using overlapping decompositions. It includes an original generalization of pairs composed of system and criterion. New expansion-contraction forms such that simultaneuosly both controllability and observability are preserved in the expanded system have been derived.

A new sufficient condition for asymptotic stability of continuous-time uncertain interconnected systems has been derived. Input delayed H_∞ decentralized control design by using the Riccati equation approach with simultaneous local delayed and non-delayed feedback has been considered. The result has been tested on simulation of control design for a building structure under earthquake excitation [9].

3.5 Adaptive Systems as Local Approximators

Bayesian statistical decision making is a well developed methodology suitable for solving variety of estimation, prediction and control problems. Inherent high dimensionality restricts its application range. It calls for methodologies that rely on local approximations around actual working point [107], i.e.

on adaptive systems. The following design line is inspected:

- Use bank of filters on the signal processed.
- Estimate a simple model of each of filtered signals.
- Design optimal predictor or controller to each model.
- Mix the results to get a common action.

This simple line calls for solution of a range of problems. At this moment, we believe that we have well grounded solutions for all steps except the first one [110, 111]. The design of filter bank that guarantees success of the whole algorithm is not satisfactory yet. A promising algorithm for constructing weakly dependent simple models is proposed in [214]. The proposed approximate minimization of mutual information may be applicable in other problems.

3.6 Advances in Nonlinear Prediction

The prediction function plays important role in the decision-making process in various application domains. A powerful forecasting method working with few assumptions appeared from chaos theory. It reconstructs the process dynamics through time delay embedding and is usually applied on univariate time series. Mixing simultaneous measurements and delay coordinates of several variables in the embedding vector allows us to fuse data from multiple sources. The work described in [230] extends the corresponding method for multivariate time series prediction. The strength of the method is successfully demonstrated on prediction of computer generated series and electrical load demand. The inherent parallelism and lack of training provide certain advantages in comparison to other nonlinear predictive models.

A new concept for the design of nonlinear prediction schemes is elaborated in [87] which in our knowledge, represents pioneering work in the strive to develop optimal forecasting systems. The global view over the design process allows control of the whole chain of important design issues: the representation problem (how to represent the state of the system through the values of the observed variables); the function approximation problem (how to estimate the prediction function using the available data); the 'credibility' problem (how to obtain the forecast using combination of plausible models). In this work the evolutionary computation paradigm has been applied to "evolve" nonlinear predictors based on developments in chaos theory and wavelet neural networks. The results suggest that exploring a diverse collection of model combination strategies is just as desirable as exploring a diverse collection of 0-level models.

3.7 Memory-Based Models in Control & Optimisation

The recent progress in database and computer technology makes it possible to use for control and optimisation of technological processes the whole process history. Being more flexible and faster than a global model and more precise and robust than a local (recent-data) model, memory-based approach offers an attractive alternative to the current paradigms. The paper [138] outlines the traditional view of local regression, shows its Bayesian extension and discusses practical choices affecting data retrieval and smoothing. Memory-based methods are especially appropriate for autonomous systems functioning in environments that are not known in advance or which are changing and in which the designers will not be able to tune the system parameters during operation. In [86] we approach the problem of system identification through the memory-based learning paradigm. If there is a continuous stream of new training data intermixed with queries, as is the situation in dynamical system identification, it is less expensive to train and query a memory-based method than it is to train and query a global nonlinear parametric model. In [85] we show that the memory-based method is a viable approach to fault detection and diagnosis. Preliminary studies prove it as more reliable for pattern recognition than some of the traditional methods. Some aspects of practical implementations (dealing with locally inadequate amounts of training data, methods for assessing the quality of the estimation, filtering of noise, identifying outliers, automatic tuning of parameters) are considered. Finally, we explore a sound approach to dealing with practical fault detection scenarios when the available database is huge.

Use of realistic models for on-line supervision of production processes increases significantly quality of fault detection and isolation (FDI) techniques. It calls, however, for a deeper understanding of the FDI problem, for development of adequate data processing techniques and software tools.

A conceptual Bayesian solution of FDI with several models has been proposed in [17]. Unlike its predecessors, it underlines the need for modelling of the fault dynamics. It also proposes alternative ways to cope with the excessive dimensionality connected with the optimal solution.

3.8 Information Geometry of Nonlinear Estimation

The lack of an analytical solution to Bayesian identification of non-linear or non-Gaussian models gave birth to a multitude of approximation algorithms. It is quite difficult for the user to compare the existing options and make an appropriate choice. Additional insight can be gained from the fact that estimation itself is an approximation problem, namely that the posterior density is closely related to the information divergence between the empirical and model distributions of observed data. The empirical distribution, the family of model distributions and the information divergence between the empirical and model distributions represent three major ingredients of the estimation problem. Any approximation of the Bayesian paradigm necessarily affects at least one of these objects. Following this pattern, in [139] and [137] we present three approximation paradigms: based on local weighting of observed data, reduction of the model family and direct approximation of the information divergence. The approaches are shown to address different application scenarios and to complement in a sense each other.

In [136], a possible extension of information geometry of nonlinear estimation to nonlinear filtering is outlined. In the framework presented, the empirical distribution of observed data is replaced by the empirical distribution of the observed output, the current system state and the future system state. The problem of state estimation is formulated then through minimization of information divergence between the model distribution and a set of empirical distributions corresponding to trajectories in the (output, state, future state)-space starting at the initial point (fixed) and ending at the terminal point (state value considered).

3.9 Fast Parallel Computations

The application area of the adaptive signal processing, control and fault detection algorithms can be broaden substantially by use of fast and parallel computation schemes [97]. The algorithms can be used in low power or high performance industrial applications. This explains the significant effort we put in this direction and got the following results:

- A novel efficient data mining method has been implemented and tested [108]. The method has been integrated into the ProDacTool software toolbox running in the Matlab 5 environment for personal computers, workstations and Linux platforms. It can also be executed on the parallel 64-bit Alpha AXP accelerator [97].
- Fast parallel algorithms for identification of systems with unknown structure have been derived. It is important that they are robust with respect to weakly informative data [208, 209, 210, 211]. Performance improvements in comparison with standard techniques were demonstrated.
- Fast parallel algorithms for adaptive control have been completed and run under Matlab 5 and on Alpha hardware.
- A library of fast identification algorithms working with fixed-point arithmetics has been implemented. It is compatible with DEC Alpha and transputer-based PC-acceleration adapters.
- A systolic recursive least square estimator (with inverse updating) has been derived. The estimator is robust with respect to weakly informative data. It is well suited for adaptive model-based predictive controllers.
- A probabilistic analysis of fixed point algorithms has been

proposed. It serves as a novel tool for design of parallel VLSI circuits for recursive identification and filtering. Research is performed within Esprit project 23544 “A High Speed Logarithmic Arithmetic Unit” [100, 98, 99, 102].

- The program package ParaMat has been designed for on-line communication from Matlab to add-in transputer or Alpha boards. The package which is compatible with the new Matlab 5.1 release, has been designed in versions for transputers, ISA Alpha boards, PCI alpha boards [101]. It can be used with Windows 95, Windows NT, or with Linux operating system.
- Rapid prototyping of fast and parallel algorithms has got an efficient support by automatic generation of the C code from Matlab scripts. The system developed is a port of commercial tool Matcom (company MathTools, USA). Our port supports execution of the C code on Alpha hardware under Linux [97].

3.10 Integration of all Cognitive Functions

Utilization of knowledge plays an important role in systems developed in our Department. We need to aid and extend our algorithmic solutions by knowledge-based approaches [6] and, in the outlook especially, by the support of knowledge acquisition. The corresponding areas of knowledge representation and utilization are well developed, and knowledge creation is well developed for applications covering relatively simple systems. Due to our orientation on real applications the extension of knowledge creation, i.e. (machine) learning to the areas of complex systems is very suitable.

We've just started to address this problem. We consider learning to be one of (basic) cognitive functions. The envisaged approach stems from observation that all cognitive functions are very intertwined. For example, learning cognitive function is interconnected with practically all other cognitive functions, like identification, (decision) implementation, (attention and reliability) control etc., and vice versa, learning participates in all remaining cognitive functions. This is why the learning problem is solved in a broader context, in a context of problem solver (PS). PS is being designed to integrate all cognitive functions into a single system [5].

Another important characteristic of the approach is the self-reflection of PS. This is applied not only to PS, but also to the whole approach. Again, it stems from realization that the results of learning research, i.e. that, what have been discovered about learning processes can be used for the design of PS. This has led, for example, to the attempt to collect "all" available knowledge, gained in the areas of artificial intelligence, machine learning, computer science, control engineering etc., and to apply it to the design of learning and PS itself.

This is a very complex task and it is, by the way, impossible to describe it precisely, in limited space, here. In the range of "all available knowledge", it is also necessary to use knowledge how to cope with complexity. Also, for example, the solution relies on knowledge from object-oriented technology, computer aided software engineering approaches and tools, Unified Modeling Language, uncertainty and inconsistency processing etc.

3.11 Notebook for the Blind

A novel version of a notebook for blind people has been prepared. Equipped with synthetic speech and the special Braille keyboard, the notebook performs many tasks in several ways. It can serve as a notetaker. Users can make lists, search through them, remove or add items. They can ask for the time or date. In addition to accurate time, there are also stopwatch, alarm clock and count-down timer functionalities. The telephony directory makes it possible to store names, phone numbers and addresses. The diary maintains users' appointments and reminders of important events.

The notebook can exchange information with a computer via an infrared port or a cable. Hence, a user can work with the notebook anywhere, and later transmit his work to a computer, or receive a large amount of information (e.g. an entire book) from a net-connected computer and read the information with the notebook whenever and wherever he or she likes.

Due to pocket dimensions (180x100x25mm), low weigh (300g) and build-in re-chargeable battery, the user has an aid for instantaneous every-day use with him. The connection to an external disk unit (100Mb ZIP-drive or 1.44Mb floppy) makes the user independent from the computer in accessing his library, placed on the disks.

3.12 Data Processing in Radiation Protection

Radiation protection is an important and challenging area for development and applications of advanced data-processing techniques. We have solved the problem of detection of trends in background dose rate measurements [186, 229]. For this, capabilities of Bayesian predictors were evaluated when data are poorly informative. Efficient algorithms have been developed and tested for a prompt monitoring in the Czech Early Warning Network and Rodos automatic run. The algorithms predict when a threshold level is likely to be crossed well before the level is actually reached. The rate of false alarms is kept very low so that the obligatory preventive actions related to suspicion of a radioactive release can be speeded up substantially.

The algorithms for judging the predictive capabilities form a part of the ABET98 toolbox and they are available together with corresponding C codes. These outcomes have been obtained within the Rodos project. In connection with this project, methodology and software tools for evaluation of radiation protection in design of nuclear power plants have been thoroughly examined [117].

3.13 Estimation Tasks in Nuclear Medicine

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. Its use has contributed to reliable estimation of various quantities met in nuclear medicine. They mostly describe the dynamics of accumulation/elimination of ^{131}I [74]. The research has reached advanced stage so that the resulting data processing is now practically tested in connection with the treatment of thyroid gland diseases [75].

Dynamic scintigraphic studies serve as an efficient noninvasive diagnostic method typically for inspecting patient's kidneys. A sequence of images in a single projection is recorded above patient who was administered by a pharmaceutical with a low-intensity radioactive marker. The gained data have to decomposed so that they reflect dynamics of individual physiological structures. This task is traditionally solved by factor analysis which, however, face non-uniqueness of the obtained decomposition.

A novel efficient solution of this problem is proposed in [109, 207]. Under clearly specified and practically acceptable conditions, vertices determining a convex set of formally equivalent solutions are searched for in the space of suitably normalized data. The algorithm, called DIAMAX, finds the correct solution within a finite and practically acceptable time.

4 Department of Stochastic Informatics

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Postgraduate Students:

Lucie Fialová	–	applied information theory
Jaroslav Franěk	–	applied information theory
Tomáš Hobza	–	nonparametric density estimation and applications in communication networks
Marek Kudrna	–	nonparametric density estimation and applications in stock market
Martina Orsáková	–	regression analysis
Martina Pavlicová	–	spectral theory of random processes

Conferences:

23 lectures, 8 of them invited, have been delivered at international conferences, including

Prague Stochastics'98, Prague, Czech Republic

3rd Japan–Central Europe Joint Workshop on Modelling and Simulation of Nonlinear Engineering systems and Related Phenomena, Bratislava, Slovakia

9th IEEE SP Workshop on Statistical Signal and Array Processing, Portland, Oregon, U. S. A.

3rd European IEEE Workshop on Computer–Intensive Methods in Control and Data Processing, Prague, Czech Republic

International Conference on Statistical Physics, Paris, France

3rd International Conference TEXSCI'98, Liberec, Czech Republic

ROBUST'98, Radešín, Czech Republic

PROBASTAT'98, Smolenice, Slovakia

MME'98, Cheb, Czech Republic

Grants and Projects:

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

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

I. Vajda: "Information-theoretic criteria of goodness-of-fit between data and probabilistic models" (GA AV ČR, A 1075709, 1997 – 1999)

J. Á. Víšek: "Combining predictions with the aid of algorithm of decomposition and composition" (GA ČR, 402/97/0770, 1997 – 1999).

P. Tichavský: "Identification of nonstationary systems" (GA ČR, 102/97/0466, 1997 – 1999)

International Cooperation

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

- Chicago, USA (Prof. A. Nehorai)
- Army Research Laboratory, Adelphi, USA (Prof. A. Swami)
- Baltimore, USA (Prof. A. Rukhin)
- Baltimore, USA (Prof. J. Smid)

- 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)
- Stockholm, Sweden (Prof. P. Händel)
- Budapest, Hungary (Prof. L. Györfi)
- Michigan, USA (Prof. V. Fabian, H. Koul)
- Wayne, USA (R. Z. Chasminskij)
- Vilnius, Lithuania (V. Paulauskas, A. Rachkauskas)
- Delft, Netherlands (Prof. J. van der Weide)
- Berlin, BRD (Prof. W. Römisch)
- Ascona, Switzerland (Prof. E. M. Ronchetti)
- London, U. K. (Prof. M. Landsbury)
- Madrid, Spain (Prof. E. Sentana)
- La Plata, Argentina (Prof. C. Muravchik)
- Linköping, Sweden (Dr. N. Bergman)
- Montpellier, France (Prof. A. Berlinet)
- Vienna, Austria (Dr. H.-P. Bernard)
- Milano, Italy (Dr.A S. M. Savaresi)
- Atlanta, U. S. A. (Prof. A. M. Gokhale)

The results of this cooperation are summarized in the published papers [18, 31, 44, 56, 68, 143, 158, 162, 164, 163, 174, 173, 218, 226, 235, 234, 236, 244, 247].

University Courses

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

University of Economics:
Informatics (P. Boček)

Czech Technical University — Faculty of mechanical engineering:
Probability and mathematical statistics, Mathematics (V. Beneš)

Charles University — Faculty of Mathematics and Physics:
Mathematical statistics, Design of industrial experiments, 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,el Statistics, Econometrics (J. Á. Víšek).

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

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

University of Alicante, Spain: Statistical methods based on ϕ-divergence of theoretical and empirical distributions (I. Vajda)
Aachen University, Germany: Robust statistics (J.Á. Víšek)

As part of teaching activities at the above Universities, fourteen diploma projects and ten doctoral theses were supervised, 1 habilitation theses refereed.

I. Vajda was a member of Scientific Boards of the Faculties of Electrical Engineering and of Physical and Nuclear Engineering, J. Á. Víšek a member of Scientific Board of the Faculty of Social Sciences, Charles University.

Researchers of the Department were members of 3 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, changepoint, optimum investment portfolios, and image and speech processing.

Altogether 52 papers have appeared during 1998.

4.1 Estimation of Average Particle Size From Vertical Projections

A new stereological relationship was derived for the average width of a collection of convex particles in a 3D microstructure. The following steps describe a practical estimation procedure. (i) Select a direction in 3D space called the vertical axis. (ii) Enclose the specimen containing the collection of particles in a slab of thickness $\triangle$, having parallel faces of area Γ. Orient the slab (our reference space) so that the vertical axis is parallel to slab faces. (iii) Observe the total projection of the reference space along a projection direction that is perpendicular to the vertical axis and uniformly random among projection directions with this property. Identify the vertical axis and the projected images of particles in the projected planar image. It is assumed that the projected images of all particles are observed in the total vertical projection. (iv) On the projected image superimpose a grid containing uniformly spaced cycloids, so that the minor axis (of length a) is perpendicular to the vertical axis. The superimposed grid must have a random position w.r.t. translations in the plane. Calculate the grid parameter β as

$$\beta = \frac{2naM}{\Gamma},$$

where M is the magnification of the projected image and n the number of cycloids in the grid. (v) Count the number of intersections I_C between the cycloids and the boundaries of the projected images of convex particles. (vi) Repeat step (v) for a number of uniform random projection directions and evaluate the average value $\bar{I}_C$. (vii) Use the total vertical projections in (v) and (vi) to estimate the total number of particles N_0 in the projected image. (viii) Substitute for β, $\bar{I}_C$ and N_0 in the new stereological equation

$$\bar{D} = \frac{\bar{I}_C}{2N_0\beta},$$

to estimate unbiasedly the average width of particles.

The result is applicable to any arbitrary collection of convex particles, the particle orientations need not be isotropic. Only intersection counts are required, it is not necessary to measure sizes of the particles in the projected images.

4.2 Processing Information

A method of integrating together information contained in individual pieces of knowledge is proposed in [110]. The pieces of knowledge are represented by probabilistic density functions. Bayesian geometric pooling is applied to integrate them into the resulting structure. The proposed methods can be applied to knowledge systems, expert systems, network-type approaches to prediction and control, etc.

A procedure transforming statistical models which are difficult to handle to more appropriate ones is stated in [214]. Twodimensional case is considered. Controlling value of f-information is stated as an example. Multidimensional case is treated in [214]. Application to controlling of the value of f-dissimilarity is presented. A heuristic procedure transforming a statistical model to a model closed to IID one is stated as an example.

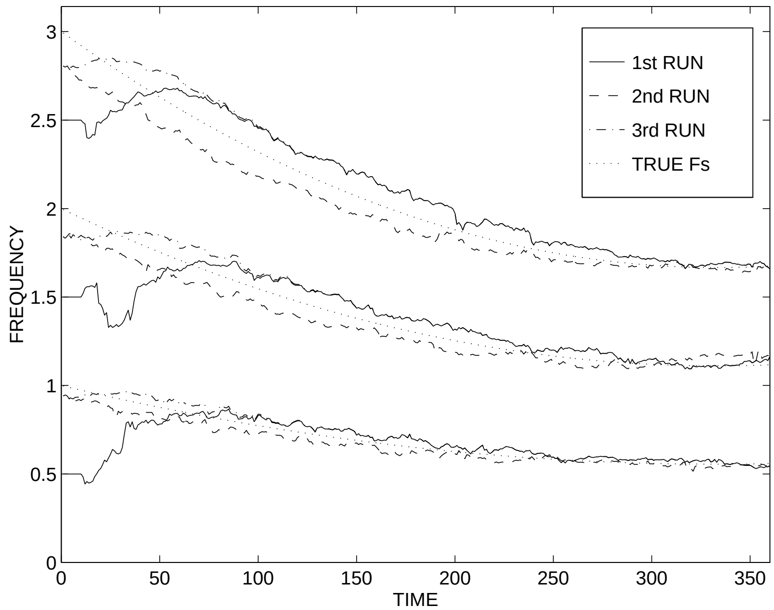
4.3 Multicomponent Polynomial Phase Signal Analysis Using a Tracking Algorithm

Polynomial phase signals are time series which have instantaneous phases modeled by polynomial functions of time. These signals are encountered for example in pulse compression radar systems, in synthetic aperture radar imaging and mobile communications. The signals often comprise several components of the type and an additive noise.

The most frequently used algorithms for estimating parameters of polynomial phase signals are based on the discrete polynomial phase transform (DPT). The DPT is a nonlinear transformation and algorithms based on DPT are known to have a relatively high SNR threshold, what means that they are sensitive to increase of the level of the additive noise presented in the signal. We proposed a quite different technique for estimating polynomial phase signal parameters, which is based on a modification of a recently developed algorithm for recursive estimation of multiple sinusoids in noise called "multiple frequency tracker", (MFT).

The technique consists in processing the data by MFT forward and backward in time (to eliminate an inevitable time delay of tracking), and fit the obtained instantaneous frequencies by polynomials of required orders. The method appears to have a superior performance compared to DPT-based methods namely at moderate or low SNR scenarios.

Our computer simulations showed that the SNR threshold of the MFT-based algorithm is significantly lower than the SNR threshold of DPT. For example, in estimating the highest phase polynomial coefficient of three components of the signal described below, the SNR threshold of DPT was 18 dB, while the SNR threshold of the MFT-based algorithm was 3 dB.



The performance of the MFT algorithm on a three component quadratic frequency-modulated signal embedded in a white Gaussian noise. SNR=-5dB for all three components. The first (forward) run of MFT is used to achieve convergence of the algorithm to true frequencies, because the true initial frequencies are not assumed to be known. The second (backward) and the third (forward) runs of MFT are used to estimate the polynomial phase parameters.

4.4 Asymptotic Properties and Optimization of Barron Estimators

In [56] and [Berlinet, Vajda, van der Meulen: About the asymptotic accuracy of Barron density estimates. IEEE Trans. Inform. Theory 44 (1998), 999–1009] was proved that applications of probability density estimators in communication require stronger inaccuracy measures than the L_1-norm or L_2-norm, namely ϕ-divergences of true densities and the estimates. For applications in the perspective area of networks with the Asynchronous Transfer Mode (ATM) protocol, the chi-square divergence (with $\phi(t) = (t-1)^2$) was found as the most convenient inaccuracy measure. As a suitable candidate for density estimator asymptotically accurate (consistent) in the set of ϕ-divergence errors has been proposed a class of estimators introduced by Barron in 1988. For this estimator Barron, Györfi and van der Meulen proved consistency in the total variation ($\phi(t) = |t-1|$) and in the information divergence ($\phi(t) = t \ln t$).

In [56] was proved that under relatively weak conditions the Barron estimator is consistent in the chi-square divergence, and in [Berlinet, Vajda, van der Meulen: About the asymptotic accuracy of Barron density estimates. IEEE Trans. Inform. Theory 44 (1998), 999–1009] this result was extended to a wider class of ϕ-divergences. In [Hobza, Kůs, Vajda: Optimal partitions and dominating distributions for Barron density estimates, Res. rep. ÚTIA 1928] the conditions on the consistency in the chi-square divergence were significantly relaxed. Moreover, for a class of densities of exponential type, there were found optimal values of parameters of the Barron estimator (the partition size and the auxiliary dominating density), which guarantee the maximum rate of convergence of the expected chi-square divergence to zero (this rate is $c\,n^{-2/5} + o(n^{-2/5})$, where the constant takes on the minimal possible value). This theoretical result was experimentally verified by extensive simulations carried out in the framework of the EU project Copernicus 579, and the optimized version of Barron estimator was added to the program package ESTTAIL, which is a part of the final software product ATMSTAT of the Copernicus project.

4.5 Asymptotic Representation of the Differences of M-estimators of Regression Coefficients

The most important result is asymptotic representation of the differences $\beta^{M,n}-\beta^{M,I_{k_n}}$, i. e. differences of M-estimators of regression coefficients for complete initial data and for data from which a subsample given by indices
$I_{k_n} = \{i_1, i_2, \dots, i_{k_n}\}$ has been deleted. The representations were found for following three cases: $k_n = \text{const}$, $k_n/n^\nu \to \xi$ and $k_n/n \to \lambda$, where ν, ξ, $\lambda \in (0,1)$.

The representation for the case when $k_n = \text{const}$ and the criterial function ψ is discontinuous contains a term which we obtain when plugging an appropriate stopping time into Wiener process. It indicates that the corresponding difference $\beta^{M,n} - \beta^{M,I_{k_n}}$, although bounded in probability, may be (and typically is) pretty large and there is no possibility how to control it. For the continuous ψ we may control the size of this difference by selecting the gross error sensitivity sufficiently small (in other words, it is sufficient to choose such ψ, maximum absolute value of which is small). In hints that it is better to avoid discontinuous ψ functions (as critical functions for M-estimators). For the cases when $k_n/n^\nu \to \xi$ or $k_n/n \to \lambda$ the asymptotic distributions have been derived, too.

4.6 The Model Characterizing the Reliability of a System Composed From Parallel Units

In the framework of statistical event-history analysis and the models based on counting processes, we proposed a simple model characterizing the reliability (the process of failures) of a system composed from parallel units. A Nelson–Aalen estimator of cumulative hazard function for components has been derived and its uniform consistency and asymptotic normality has been proved, the latter meaning the convergence of normalized residual process to a Wiener process. On this basis, the goodness-of-fit test and the test of homogeneity have been constructed.

In the same field, the processes cumulating random increments at random moments were examined. The model was again based on the counting process concept. We derived the compensator – martingale decomposition of the process and an estimator of the cumulative rate of the process. It was proven that the estimator was also uniformly consistent and asymptotically normal. The test procedures were proposed both for assesing the goodness-of-fit and for comparison of two sets of processes [255, 257].

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František Včelař	–	Generalized choice model and Arrow problem in many–valued logical environment.

The Department concentrates on theoretical economic research in the following areas:

- Stochastic economics, econometrics and econometrics modelling,
- uncertainty processing in expert systems,
- stochastic differential equations with application to capital markets,
- stochastic optimization,
- fuzzy set theoretical approach to desicion–making.

Grants and Projects:

- A. Derviz: *Stochastic General Equilibrium Theory of Emerging Capital Markets* (Grant GA AV No. A 8085701)
- V. Kaňková: *Modelling and Decisions in Time-Dependent Economic Systems* (Grant GA ČR No. 402/98/0742)
- M. Mareš: *Fuzzy Set Theoretical Models of Cooperative Behaviour of Economic Subject.* (Grant GA ČR No. 402/96/0414)

- M. Mareš: *Tools and Methods of Mathematical Informatics Cybernetics and Information Transmission* (Key Project of the Academy of Sciences of the Czech Republic No. K 1075601)
- K. Sladký: *Complex Economic Systems and Decision Making under Uncertainty*. (Grant GA ČR No. 402/96/0420)

University Courses:

- *University of Economics, Prague*
  - J. Kodera - Capital Markets
- *Faculty of Social Sciences of the Charles University :*
  - A. Derviz - International Finance A1, A2
  - V. Kaňková - Decision in Economics: Deterministic and Stochastic Optimization
  - M. Mareš - Game Theoretical Models of Economic Behaviour
  - K. Sladký - Stochastic Processes in Economy
  - F. Včelař - Probability Theory and Mathematical Statistics
  - M. Vošvrda - Theory of Probability and Statistics
  - M. Vošvrda - Theory of Economic Cycles
  - M. Vošvrda - Theory of Capital Markets
- *Faculty of Electrical Engineering of the Czech Technical University:*
  - M. Mareš - Theory of Games (doctoral study)

Our visitors:

- Prof. Nico van Dijk (University of Amsterdam)
- Dr. Viliam Páleník (Institute of Slovak and World Economics of SAS, Bratislava)
- Ing. Jaroslav Vokoun (Institute of Slovak and World Economics of SAS, Bratislava)
- Dr. René Henrion (Weierstrass Institute for Applied Analysis and Stochastics, Berlin)
- Prof. Thomas Whalen (Minnesota State University, USA and Institute of System Research, Warsaw)

Diploma and Doctoral projects:
Diploma:

- Faculty of Mathematics and Physics of the Charles University
  (supervisor V. Kaňková - 1)
- Faculty of Social Sciences of the Charles University (supervisor M. Vošvrda - 1)
- Faculty of Nuclear Physics and Engineering of the Czech Technical University (supervisor M.Vošvrda - 2)

Doctoral:

- Faculty of Mathematics and Physics of the Charles University
  (supervisor V. Kaňková - 1)

- Faculty of Social Sciences of the Charles University (supervisor M. Vošvrda - 2)
- Faculty of Transport Engineering, Czech Technical University
(supervisor M. Mareš - 1)

Conferences Participation:

1. Prague Stochastics '98, 23. - 28. 8. 1998, Prague (Mareš – Organizer of section : Models of Uncertainty)
2. Exchange Rate Impact on Research Economy, Lublaň (Slovenia) 1998 (Derviz)
3. Monetary Policy Design for Transition Economies, Bordeaux (France) 1998 (Derviz)
4. VII International Conference on Stochastic Programming, Vancouver (Canada) 1998 (Kaňková)
5. Computational Economics, Cambridge (United Kingdom) 1998 (Vošvrda)
6. Quantitative Methods in Economics, Bratislava (Slovak Republic) 1998 (Kaňková, Sladký)
7. Econometric Day '98, May Prague (Kaňková, Kodera, Sladký, Vošvrda)
8. Fall Econometric Day '98, Brno (Kaňková, Kodera, Sladký, Vošvrda)
9. International Conference on Mathematical Methods in Economics, Cheb 1998 (Kaňková, Kodera, Sladký, Vošvrda)

10. Mathematical Methods in Economy and Industry, Liberec 1998 (Kaňková, Kodera, Sladký)
11. Optimization Techniques and Applications, Perth 1998 (Mareš)
12. Exchange Rate Impact on the Real Economy, Lublaň (Slovenia) 1998 (Derviz)
13. Monetary Policy Design for Transitional Economies, Bordeaux (Francie)1998 (Derviz)
14. Advanced Topics of Monetary Analysis, Bank of England, London (Great Britain) 1998 (Derviz).

International Cooperations:

Long term cooperation with Department of Economic Sciences and Econometrics – University of Amsterdam, including a visit of Sladký to Amsterdam and two visits of Prof. N. M. van Dijk to Prague

Members of the Department participated in joint research with their colleges from University of Amsterdam (Department of Economic Sciences and Econometrics), University of Cambridge, University of Bath, London Business School and Federal University of Rio de Janeiro.

Public Utility Services:

Three members of the Department (Kaňková, J. Kodera, and M. Vošvrda), were voted fellows of the Czech Econometric Society.

M. Vošvrda, and E. Dostálová are editors of the Bulletin of the Czech Econometrics Society.

M. Mareš is Tresaurer of the Czech Society for Cybernetics and Informatics and member of the American Mathematical Society, member of Editorial Board of journal Kybernetika, and till May 1998 Member of the Academic Council of the Academy of Sciences of the Czech Republic.

K. Sladký is Managing Editor of journal Kybernetika.

J. Kodera, K. Sladký have become members of the Economic Sciences Division of the Grant Agency of the Czech Republic.

R. Mesiar has become member of Editorial Board of the international journal Fuzzy Sets and Systems.

M. Vošvrda has also participated in a TEMPUS program for forming lectures on Capital Markets at Universities in Europe (Limerick - Ireland).

5.1 Markov and Semi-Markov Processes

Sensitivity Analysis

A systematic attention was also paid to the sensitivity analysis of Markov and semi-Markov models. In particular, succinct proofs of existing basic perturbation formulas for the steady state distributions of discrete-time finite Markov chains when both the original and the perturbed matrix have a single recurrent class were elaborated. Using a uniformization techniques also perturbation formulas for the steady state distributions of continuous-time Markov chains are obtained. Particularly, a recently derived formula for infinitesimal perturbation analysis is included both for the discrete- and continuous-time setting. [216] Moreover, a uniformization technique was also studied for nonhomogeneous

Markov processes and its extension to the case when transition rate matrices are replaced by general matrices with nonnegative off-diagonal entries [248].

5.2 Dynamic Economic Systems

A Speed of Adjustment

Dynamical aspects of macroeconomic interaction or dynamical input-output models under uncertainties were investigated. Such an approach is useful for modelling and calculating the interactions between different industrial markets as well as their capital flow to and from the "state" market. We focus our attention on the dynamical aspects of the input-output model under uncertainties. The speed of adjustment to the steady state solutions was analyzed under interval uncertainties in the technological coefficients of the model and the sensitivity of the output on small perturbation of the input parameters [217].

Macroeconomics and Capital Markets

Macroeconomics in the Czech Republic during 1998 is described in [260]. A description of the Capital Market in the Czech Republic for year 1998 is introduced in [258], [118]. A description of the Slovak Capital Market for year 1998 is introduced by Vokoun J. in [261]. Entrepreneurial behavior of agents on capital markets were analyzed on four Stock Exchanges (Amsterdam, Lisbon, Prague, and Bratislava) by neural networks analysis [261]. The Capital Assets Price Model was analysed on Prague Stock Exchange [259]. For detailed description of the results please see in [261]. Next, the test of risk aversion of agents on Prague Stock Exchange was performed with the following conclusion: An existence of the risk aversion was not confirmed by our analysis. It means that the Czech capital market evaluates an investor's risk lightly [262].

The Efficient Market Hypothesis

The efficient market hypothesis was tested on Prague Stock Exchange. It was demonstrated that the stock returns behaviour on the Czech capital market is not consistent with the weak-form efficiency market hypothesis because high autocorrelation of returns is present. Moreover, contrary to the random walk hypothesis, stock price returns are heteroscedastic. We use the GARCH (1,1) model to analyze the heteroscedasticity. We observe, that the volatility increased in 1997, especially during political crises. Finally, we explore by means of the GARCH-M model, the extent of risk aversion on the Czech capital market. However, we conclude that this element is not statistically significant and therefore the hypothesis of risk neutrality cannot be refuted [262]

International Finance

The model of shadow asset prices, previously derived by A.Derviz from a version of the stochastic maximum principle, was applied to the following three problems of theoretical and empirical finance theory. A model of American options on currencies was constructed to explain the smoothing of sharp exchange rate regime changes by the observed international trade flows. The shadow price approach to the stochastic general equilibrium provided a model of the foreign exchange market serving as an international version of the Consumption-based Capital Asset Pricing Model. The generalized uncovered asset return parity condition derived from it constitutes a tool for the evaluation of equilibrium exchange rates.

The risk-conditioned properties of the consumption function of the Czech economy was evaluated [42]

5.3 Uncertainty Cooperation Models

Fuzzy Set Theoretical Models

The research regarding the mathematical modelling of group decision making and, especially, coalition forming under uncertainty supported by grant project has continued also in this year. The grant was finished and the achieved results were summarized in several publications. The main attention was focused to the possibility of coalition structures, i.e., the structures of achievable cooperating groups which can be formed under the assumption that the information about the expected profits is only vague, for example, described by some verbal characterization. The uncertainty connected with the expectation of profits influences also the uncertainty about the formed coalitions. The ability of players to cooperate is influenced, among others, also by the existence of superadditivity (or subadditivity) in the game, by its convexity and other properties. The fuzzy knowledge of the input information about the expected profits is reflected, especially, by the fuzziness of the properties mentioned above.

The research realized in 1998 was developed into three main streams. The first one of them was especially focused to the proper game theoretical properties of fuzzy extensions of coalition games, both with and without side-payments. The uncertainty connected with the achievability of particular coalitions and pay-offs was quantified on the basis of the fuzzy set theoretical characterization of the input information. The publications including these results are to appear in 1999. The second stream dealt with an alternative representation of fuzzy quantities which appears more adequate to the mathematical models in which many operations with fuzzy numbers or fuzzy quantities are needed. In such cases the alternative model of fuzzy quantities and algebraic operations with them enables to limit the final uncertainty of the achieved results and to keep it in realistic extent [155], [159]. This alternative approach to fuzzy quantities is more effective if so called triangular norms are used for the description of some operations. Further development of the theory of triangular norms was solved in frame of the third stream of the research and new generally valid results were achieved [165]. Parallelly with this research also fuzzy set theoretical approach to critical path method , [154] and to capital market models [153], [156], [157] were investigated.

5.4 Stochastic Programming and Decision in Economy

Stochastic programming problems can serve as a mathematical tool for many economic and social activities that can be (in some way) controlled. These mathematical problems, depending generally on a probability measure, are (from the mathematical point of view) usually very complicated. Moreover, in applications mostly it is necessary to replace the underlying probability measure by some its approximation. Consequently, to any responsible application it is, first necessary, to study the properties of the problems, in details. To this end it was went on in the theoretical investigation. The main attention was paid to the multistage stochastic nonlinear programming problems, especially to the properties of individual objective functions in the decomposed form of the problem. The achieved results were furthermore applied to empirical estimates in the multistage stochastic programming problems (mostly with Markov type dependence) [106]. Furthermore, empirical estimates of probability multifunctions were investigated [103]. The paper follows the work [104], where generally the multifunctions in stochastic programming were investigated. It is possible to await that the results of the last two papers can be in future applied to a special type of the multistage stochastic programming problems with probability constraints.

Simple (static and dynamic) models of an unemployment and a restructualization was constructed. Evidently, dynamic version of this model corresponds just to the multistage stochastic programming problem with the probability constraints.

6 Department of Pattern Recognition

Head of Department:

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Secretary:

E. Maléřová		Phone & Fax: (+420-2) 688 3031 e-mail: pudil@utia.cas.cz

Research Fellows:

J. Grim	-	Probabilistic neural networks, probabilistic expert systems e-mail: grim@utia.cas.cz
M. Haindl	-	Spatial data modelling, virtual reality 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:

P. Somol	-	Statistical Pattern Recognition
R. Vrňata	-	Statistical Feature Selection
P. Žid	-	Image Segmentation
V. Havlíček	-	Texture Synthesis
P. Paclík	-	Statistical Pattern Recognition

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
- P. Pudil, "Non-classical approaches to decision-making"
  Grant Agency of the Czech Republic; No. 402/97/1242
- J. Grim, "Probabilistic neural networks"
  Grant Agency of the Academy of Sciences of the Czech Republic; No. A2075703
- M. Haindl, "VIRTUOUS - Autonomous Acquisition of Virtual Reality Models from Real World Scenes"
  European Union project INCO Copernicus; No. 960174
- M. Haindl, "Virtual Reality"
  Grant of the Ministry of Education; No. OK276
- M. Haindl, "Virtual Reality"
  Hewlett Packard Grant; No. ISE-86L8-13

PhD Projects:

- 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 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

- Faculty of Mathematics, Charles University
  Havlíček V.: “Texture Synthesis”
  Supervisor: M. Haindl

- Faculty of Transportation Sciences, Czech Technical University, Prague
  P. Paclík: ”Statistical Pattern Recognition in Traffic Engineering”
  Supervisor: J. Novovičová

MSc Diploma Projects:

- Faculty of Management, University of South Bohemia
  K. Beránek: “Application of feature selection methods in multiple stepwise regression analysis”
  Supervisor: P. Pudil

- Faculty of Transportation Sciences, Czech Technical University, Prague
  P. Paclík: ”Automatical Classification of Road Signs”
  Supervisor: J. Novovičová

University Courses:

- Faculty of Electrical Engineering, Czech Technical University
  M. Haindl: "Pattern Recognition"

- 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: "Probability Theory"
  J. Novovičová: "Mathematical Statistics"
  J. Novovičová: "Advances in Mathematical Statistics" (doctoral study)

- 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:

- 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 Committee "Statistical Techniques in Pattern Recognition"
P. Pudil — Governing Board member of the IAPR
P. Pudil — External PhD examiner for Cambridge University

- Co-operation on statistical approach to pattern recognition:
  P. Pudil, J. Novovičová, J. Grim — University Surrey, GB; University of Valencia, Spain
  P. Pudil, J. Novovičová, P. Paclík — Delft University of Technology, Pattern Recognition Group, The Netherlands
  P. Pudil — University of Cambridge, GB

Conferences

The research results of the department members have been presented at several international conferences including:

- IAPR International Workshops SSPR'98 and SPR'98, Sydney, August 11 - 13, 1998, (cf. [195], [59])
- 3rd European IEEE Workshop CMP'98, Prague, September 7 - 9, 1998, (cf. [178], [51])
- 14th International Conference on Pattern Recognition ICPR'98, Brisbane, August 16 - 20, 1998, ([53], [64])

- 22. Jahrestagung der Gesellschaft fuer Klassifikation e.V., Dresden, March 4 - 6, 1998, (cf. Grim - to appear)
- 7th International Workshop on Robotics in Alpe-Adria-Danube Region, ASCO Art: Bratislava, 1998, (cf. [61], [65])
- Week of Doctoral Students 1998, (cf. [60])

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.

6.1 Statistical Pattern Recognition

The normal distribution is well known to have shorter tails than distributions which can occur in applied problems and a t-distribution with moderate number of degrees of freedom is often regarded as a better fit. In the paper [178] the approach to multiclass classification based on the multivariate Student's t-mixtures model for class densities has been developed. Our proposal for classification has the following features: (a) the classes are modelled as mixtures of

Student's t- distributions rather than mixtures of Gaussian distributions; (b) the expectation-maximization (EM) algorithm is used to fit mixtures of t-distributions by maximum likelihood method; (c) the maximum likelihood estimations of the mixtures component mean vectors and covariance matrices are robust in the sense that the data with large Mahalanobis distances are weighted down.

The so called "knowledge-based approach to feature selection" has been developed [193, 192]. It is derived from the fact that the choice of the optimal methods for selection of feature variables in statistical pattern recognition depends basically on the level of a prior knowledge about the problem which the user has. It concerns a number of conditions, like the aim of dimensionality reduction, the original dimensionality of input data, the level of prior knowledge of underlying probability structure, the size of the training sets, etc. With the aim to ease the situation, the FS Toolbox is being developed, together with a consulting system which should guide a less experienced user through the method included into the package [194, 195]. The core of the package will be formed by the novel methods we have developed ourselves i.e. the floating search methods and the methods based on finite mixtures.

It is well known that log-likelihood function for finite mixtures usually has local maxima and therefore the iterative EM algorithm for maximum-likelihood estimation of mixtures may be starting-point dependent. In the paper [53] we have proposed a method of choosing initial parameters of mixtures which includes two stages: (a) computation of nonparametric optimally smoothed kernel estimate of the unknown density, (b) optimal weighting of the smoothed kernel estimate and using essential kernels as the initial estimate of the mixture. All the optimization tasks make use of a suitably modified EM algorithm. The properties and computational aspects of the proposed method are illustrated by a numerical example and some application possibilities are considered.

6.2 Probabilistic Neural Networks

It has been shown in the framework of multilayer probabilistic neural networks that the involved information preserving minimum-entropy transform tends to produce features of low statistical complexity (cf. [54]). It is a well known empirical experience that, with increasing dimension, the input space becomes "sparse" and, simultaneously, the multivariate components of finite mixtures become increasingly nonoverlapping. Consequently, the a posteriori probabilities of components can be looked upon almost as binary variables. It is shown that binary approximation of the information preserving transform essentially simplifies the underlying probabilistic neural network and the related optimization problem. The computation of neuron responses amounts to competitive evaluation of simple linear expressions. We derive bounds of the information loss caused by a binary approximation and show that the information loss approaches zero with increasing approximation accuracy. The reliability of the proposed scheme can be improved by considering multiply parallel solutions for each layer.

The probabilistic approach to neural networks is based on finite mixtures and their optimization by means of EM algorithm which is an off-line procedure in its standard form. However, the existence of a sequential version of the EM procedure is an important condition of neurophysiological plausibility. For this reason a sequential learning scheme has been proposed (cf. Grim, to appear in Proceeding of the 22nd Meeting GfKl'98, Dresden, 1998) which is equivalent to the EM algorithm in case of a repeatedly applied finite set of observations.

6.3 Image Segmentation

Two novel range image segmentation algorithms were developed. A robust planar face range data segmentation algorithm was proposed [64] which combines a random field-based discontinuity detector with a efficient line-based region growing. The segmentation quality and the speed of performance of this algorithm is among the best published algorithms.

The second segmentation algorithm [65], [66] segments range images with general face objects. The method uses an efficient 1D cubic spline representation of general surfaces.

A fast algorithm for unsupervised color texture mosaic segmentation has been developed [59]. This algorithm does not require any knowledge about textures present in a segmented scene. The method is fully adaptive, numerically robust but still with moderate computation complexity.

6.4 Markov Random Fields

A new multiresolution approximation of a non-causal Gaussian Markov random field was proposed [61], [62] together with its parameter estimation and synthesis. Markov random field generally lose their Markovianity if they are decomposed into multiple resolution factors and usual approximations are computationally demanding. The proposed model enables to describe complex spatial relations due to simple independent Markov submodels for single spectral and frequency factors. This model was successfully applied to natural color texture modelling [61], [60].

In the area of causal random field models we have proposed [63] an adaptive simultaneous autoregressive model-based algorithm for fast reconstruction of image scratches. The method does not assume any knowledge of reconstructed data, missing data in color image scratches are reconstructed using spatial and spectral correlation from their corresponding neighbourhoods.

7 Department of Image Processing

Head of Department:

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Secretary:

Jana Švarcová	–	e-mail: imgproc@utia.cas.cz

Research Fellows:

Jiří Boldyš	–	3-D invariants
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Dana Klimešová	–	temporal and context analysis, texture analysis e-mail: klimes@utia.cas.cz
Stanislav Saic	–	image processing in geophysics e-mail: ssaic@utia.cas.cz
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Grants and Projects:

- J. Flusser - Recognition of radiometrically degraded digital images by the method of invariants (Grant Agency of the Czech Republic, No. 102/96/1694)

- 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 - Combined invariants and their using for recognition of 2-D objects (Grand Agency of the Czech Republic, No. 102/98/P069)

- J. Flusser - Computer Aided Fractography (Grant Agency of the Czech Republic, No. 106/97/0827 – jointly with the Faculty of Nuclear Sciences and Physical Engineering CTU)

University Courses:

Jan Flusser	–	"Digital Image Processing" at the Faculty of Mathematics and Physics, Charles University, Prague.
	–	supervisor of six Ph.D. students
	–	supervisor of diploma theses.
	–	"Image Processing and Pattern Recognition", Faculty of Mathematics and Physics, Charles University, Prague.
Dana Klimešová	–	"Applied Computer Science" at the Faculty of Economics and Management, Czech University of Agriculture, Prague.
Stanislav Saic	–	"Applied Computer Science" at the Faculty of Science, Charles University, Prague.

The research activity is focused on the following areas:

- theory of the invariants
- recognition of distorted images and patterns
- texture and context analysis
- image restoration
- applications in remote sensing, astronomy, medicine, archeology, geodesy and geophysics

7.1 Fast Calculation of Image Moments

Image moments and various types of moment-based invariants play very important role in object recognition and shape analysis. The $(p+q)$th order geometric moment M_{pq} of a grey-level image $f(x,y)$ is defined as

$$M_{pq} = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} x^p y^q f(x,y)dxdy. \tag{1}$$

In the case of a digital image, the double integral in eq. (1) must be replaced by a summation. The most common way how to do that is to employ the rectangular (i.e. zero-order) method of numeric integration. Then (1) turns to the well-known form

$$m_{pq} = \sum_{i=1}^{N}\sum_{j=1}^{N} i^p j^q f_{ij}, \tag{2}$$

where N is the size of the image and f_{ij} are the grey levels of individual pixels.

Since direct calculation of discrete moments is time-consuming, a large amount of effort has been spent to develop effective algorithms. We proposed a new method for moment calculation in the case of a sequence of objects. All methods published up to now have considered single object only. However, in practical shape recognition tasks we have to deal with a large number of objects. Since the same set of moments is to be calculated for each object, it would be highly desirable to pre-calculate some operations which are common for all objects in advance. Thus, we divided the algorithm in two stages. The first one, containing relatively complex operations, is performed only once and its results can be used for any object. The second stage contains very simple operations and must be performed for each individual object. This decomposition makes the method extremely effective for extensive object recognition tasks with hundreds of objects under investigation. Both stages of the method were effectively described by matrix algebra and implemented in MATLAB 5.1. [47], [46].

7.2 Point-Based Projective Invariants

One of the important tasks in image processing and computer vision is a recognition of objects on images captured under different viewing angles. If we restrict ourselves to planar objects only, then the distortion between two frames can be described by projective transform. Feature-based recognition of such objects requires features invariant to projective transform. One group of such invariants are point-based ones. They are defined on point sets.

A projective invariant can be defined for at least five points. The simplest one is a five-point cross-ratio.

If we do not know correspondence between the points in the set, we need also permutation invariants, therefore we must use a ratio of two polynomials of the cross-ratio, whose roots lay on the following curves:

$$\begin{aligned} a_1^2 + b_1^2 &= 1, \\ (a_2 - 1)^2 + b_2^2 &= 1, \\ a_3 &= \tfrac{1}{2}, \end{aligned} \tag{3}$$

where there are following relations between the roots:

$$a_2 = 1 - a_1, \; b_2 = b_1, \; b_3 = \frac{b_1}{(a_1 - 1)^2 + b_1^2} = \frac{b_2}{a_2^2 + b_2^2}, \tag{4}$$

where a_i and $b_i, i = 1, 2, 3$ are real and imaginary parts of the roots.

If invariants for more than five points are needed, they can be constructed by following way:

$$I_{1,k} = \sum_{Q \in C_5^n} I_1''^k(Q), \quad I_{2,k} = \sum_{Q \in C_5^n} I_2''^k(Q), \quad k = 1, 2, \ldots, n-4, \tag{5}$$

where I_1'' and I_2'' are normalized 5-point projective and permutation invariants.

If the sets can include some wrong points, i.e. points without counterpart in the other set, we must use some other method.

We can use five-point projective and permutation invariants and compute the distance in the feature space between invariants of each five points from the input image against invariants of each five points in the reference image. Nevertheless, it was found that wrong five points often match one another randomly, this false match can be better than the correct one and we must search not only the best match, but also each good match. Therefore we find the first b best matches and the full search algorithm from the previous section is applied on each pair of five-tuples corresponding each match. The number b was chosen as $\binom{max(n,\ell)}{5}$, but this number is not critical. Note: the total number of pairs of five-tuples is $\binom{n}{5}\binom{\ell}{5}$.

7.3 Reliable Estimation of Transformation Parameters of Nonlinear Geometric Transformation

The research is focused on geometric transformation of images. A general method for determination of probability density function (pdf) of transformation parameters was designed. The method is based on two procedures:

1. nonlinear Bayesian estimation of parameters,

2. probability distribution of an approximated function of random variables.

The both procedures constitutes two phases of experimental data processing.

In the first phase a posterior probability density function of estimated parameters is determined which considers linearization error of the nonlinear model. If the probability distribution of the measured data (coordinates of points in an image) is close to normal distribution and the nonlinearity is only slight, some well-tried algorithm for linear estimation can be used. In such case, analytical form of pdf of the measured data is modified to utilize advantages of linear model and simultaneously to keep the linearization error under consideration. The outcoming posterior distribution is normal, so that the designed procedure belongs to the class of methods based on approximation of a posterior distribution by normal distribution. In fact, the probability distribution of measured data is approximated (see [220]).

If the nonlinearity is significant, then both phases of processing has to be used. The magnitude of nonlinearity is lowered with the aid of a transformation of the estimated parameters. The transformed model has to be so close to a linear model that the first phase can be applied. In such a case probability distribution of the original parameters has to be derived. For this purpose the inverse transformation has to be applied to the probability distribution of the transformed parameters. To efficiently compute the inverse transformation it is necessary to approximate it in most cases. Then the second of processing comes. The probability distribution of the original parameters is reliably derived on the basis of roughly estimated magnitude of the approximation error.

The second phase was applied to the nonlinear feature extraction as well (see [221]).

This work has been supported by Grant A 2075603 of the Academy of Sciences of the Czech Republic.

7.4 Context Window for Training Learning and Texture Classification

Textures are an integral part of every image, important component of human visual perception and the texture analysis is used in the large variety of applications from the medical imagery, industrial images, computer vision to the remote sensing applications. Textures are usually characterized by the given number of features (most of which are statistical) computed from the rectangular image segment i.e. subimage of defined size. The training set of known samples is not complete. The sensitivity to translation, rotation or resolution is very changeable in depending on the type of textural object. After learning, we can expect an optimal recognition ability for the training set but we can meet difficulties with generalization for unknown objects.

Contextual information can be taken into account in a number of ways. It can be considered, when the feature space is constructed, as a part of mapping of the object into a vector space. We include the features that hold information about arrangement and cross-relations in the neighbourhood. Another way is to use the context within the analysis or in the course of the classification. In [116] the case is discussed when the contextual information is drawn from the neighbouring pixels tend to be the same class and a new approach of feature selection algorithm is presented.

It can be the significant limitation of the real application to find great enough training sets to be able to estimate statistical parameters with sufficient exactness. Having training samples of size 64 x 64 and subimage of size 16 x 16 it means we will obtain only 16 points as a result of the mapping into the feature vector space. In the case of sample size 8 x 8 it is 64 features. It is really not too much when we take into the consideration that during the phase of training we have to determine the distribution of recognized objects in the feature vector space as exact as possible to achieve good results of the recognition. It was the reason of our effort on the field of sliding window and it's using for training learning and texture classification, see [115].

The sliding window increases the number of samples and consequently the number of features which can be successfully used to investigate the features stability, improves the feature selection and the accuracy of the classification and moreover it facilitates the border effect. On the other hand the time and space complexity of algorithm also increase. The computation can be performed directly on the original image. In order to confirm our hypotheses and to demonstrate the results of feature selection and the texture recognition we used the digitized images from the optical microscope consisting from 10 samples of magnetic domain structures (see web pages).

7.5 Multichannel Blind Deconvolution

In many science and engineering applications due to the imperfections in real imaging process the observed image is just a degraded version of the original image. These degradations are mainly caused by blur and noise. Usually this degradation is modeled by a convolution of the original image with linear shift invariant point spread function.

The goal of the image restoration is to obtain an estimate of the original image. This estimate is usually called *restored image*. The basic approach to this problem assumes a priori knowledge of the point spread function and some parameters of the noise. But this assumptions may not be met in practice.

In blind image restoration the restoration algorithms do not require the knowledge of the blur. Only partial information such as nonnegativity, known finite support or symetry is required instead. Multiply blurred images are available in many applications. Examples of such a sensor "diversity" include remote sensing, where the same scene may be observed at different time instants through a time varying inhomogeneous medium such as the atmosphere; electron microscopy, where the micrograph of the same specimen may be acquired at several different focus settings; or broadband imaging through a fixed medium which has a different transfer function at different frequencies. In this case we talk about *multichannel blind deconvolution*.

In the typical case the methods are based on minimizing of the following functional:

$$J(\hat{f}, \hat{h}_i) =$$

$$= \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \sum_{\forall i} \| g_i(x,y) - \hat{f}(x,y) * \hat{h}_i(x,y) \| dxdy + J_1(\hat{f}, \hat{h}_i)$$

The functional J_1 represents the conditions the estimate of the image and of the point spread functions must satisfy. This can prevent the trivial solution (h_i are the Dirac functions) and also reduces the ambiguity of the solution.

Usually the methods assume some statistical presumptions about the image and the blurs and solve this functional on statistical basis via maximum likelihood approach. The drawback of these methods is their heavy computational burden.

We developed an algorithm that is computationally efficient and does not need any statistical presumptions about the image. Also *a priori* knowledge can be very easily incorporated. The idea is based on the iterative algorithm first reported by Ayers and Dainty. We have extended the original algorithm for the case of multiply blurred image and also improved its convergence properties. The extension for multichannel deconvolution was done by introducing a 3D representation of the blurred image. Convergence properties were improved by using an iterative Wiener filter instead of ordinary one. Successful application of the new method to astronomical image deconvolution can be found in [126].

7.6 3-D Hydrodynamical Modelling of Viscous Flow Around a Rotating Ellipsoidal Inclusion

In ductile shear zones and in metamorphic rocks in general, the geometry of fabric is a valuable source of information on the kinematics and dynamics of flow. To understand the fabric development, structural geologists use numeric al or analogue modelling of behaviour of rigid objects embedded in a viscous matrix. Numerical models are based on continuum mechanics and, with more or less accuracy, describe the motion of a rigid body and/or the flow around it. The aim of our work is the presentation of a procedure based on the approach of Jeffery that enables numerical modelling of the flow around rigid ellipsoidal inclusions. Jeffery's equations were re-developed and corrected, and we found an efficient way to compute the elliptic integrals that are needed for the solution. The model of Jeffery is based on some assumptions (slowly moving Newtonian fluid, non-interacting particles) that are not always strictly valid in nature. Despite this fact, the model represents a valuable tool for studying the behaviour of rigid objects in a viscous matrix and the number of its applications will probably increase. In the field of geosciences, the our approach can be used, for modelling the development of inclusion trails in porphyroblasts.

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