

ACTIVITY REPORT '2001

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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 view of mathematical modelling, decision making, automatic control and signal processing.

This report gives an overview of our research activities in 2001. It is of course not possible to give a full account of the research results here. The results selected are divided into sections representing the eight research departments of the Institute. Each department is briefly introduced and its overall activity is described. The report is completed by a list of works published and/or accepted for publication.

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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.

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. Main developments in the 1990s are in recursive nonlinear estimation, usual data reconstruction and pattern recognition. Currently ÚTIA holds research grants from many domestic and foreign agencies.

The scientific library of ÚTIA contains more than 32.000 books and periodicals. The computational resources of ÚTIA include 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*. It regularly organizes the Prague Conferences on Information Theory as well as other events sponsored by the International Federation of Automatic Control (IFAC), Interna-

tional 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 of Cybernetics and Informatics.

ÚTIA has developed close research and teaching contacts with many academic and industrial institutions. The Institute has achieved joint accreditation licence for organizing post-graduate study programmes with the Faculty of Mathematics and Physics of the Charles University and with the Faculty of Nuclear and Physical Engineering of the Czech Technical University. An analogous joint accreditation with the Faculty of Electrical Engineering of the Czech Technical University is under preparation. It is affiliated with several institutions of higher education, including the Czech University of Technology and University of Economy, and Charles University, and coordinates Central European Graduate School in Systems and Control Theory. It houses the Prague Technology Center, a joint research establishment with Honeywell, Inc.

The Institute coorganized the

- 1st IFAC Symposium on Systems Structure and Control, Prague, August 29–31, 2001
- International Conference on Artificial Neural Networks and Genetic Algorithms. Prague, April 10–14, 2001

and participated in the organisation of numerous other conferences.

Among others, the Institute is an organizer or coorganizer of

- 24th European Meeting of Statisticians, August 19–23, Prague
- Mathematical Methods in Economy, September 2002, Prague
- European IT Research Programme (IST) Successful Proposal Writing, January 17, 2002
- e-Business and e-Work, October 16–18, 2002, Prague

Contents

General	1
1 Department of Decision-Making Theory	11
1.1 Flow problems with incompressible fluids	14
1.2 Shape of elastic bodies in unilateral contact	15
1.3 Non-graphical and graphical descriptions of conditional independence	16
1.4 Convex cores of measures	17
2 Department of Control Theory	19
2.1 Linear Matrix Inequalities for Polynomial Matrices in Control	26
2.2 Pole Placement and H_2 Control	27
2.3 The Matrix Completion Problem	28
2.4 Modules Over Noncommutative Rings for Nonlinear Systems with Delays	28
2.5 Numerical Methods for Polynomial Matrices	29
2.6 Controllability and Stabilizability of Nonlinear Systems	29
2.7 Robust Output Regulation of Nonlinear Systems . . .	30
2.8 Output Feedback in Nonlinear Systems	30
3 Department of Adaptive Systems	33
3.1 ProDaCTool: Operator Support	41
3.2 Model validation in high dimensions	42
3.3 Non-linear estimation and change detection of stochastic systems	43
3.4 Computer-Aided Design of Adaptive Controllers . . .	44
3.5 Robust Decentralized Control of Large-Scale Systems	46
3.6 Robust Control of Multivariable Systems	47
3.7 Continuous-time modelling and hybrid adaptive control	48
3.8 Integration of all Cognitive Functions	49

3.9	<i>Customisation of the RODOS system for ČR</i>	50
3.10	<i>Estimation Tasks in Nuclear Medicine</i>	51
3.11	<i>MIAPS – Design of a Computer Module for Information Analysis of Time Series of Autonomous Protein System Responses</i>	52
4	<i>Department of Stochastic Informatics</i>	55
4.1	<i>Bayesian analysis of log Gaussian Cox processes for disease mapping</i>	61
4.2	<i>Computer module for simulation of communication net- work traffic</i>	62
4.3	<i>Problems of estimating capability indices in SPC</i>	62
4.4	<i>Filtering, predictive, and smoothing Cramér–Rao bounds for discrete-time nonlinear dynamic systems</i>	63
4.5	<i>Nonparametric statistical information theory</i>	64
4.6	<i>Parametric statistical information theory</i>	64
4.7	<i>Prognosis and optimization in data networks</i>	65
4.8	<i>Consistency of the least weighted squares estimator</i>	65
4.9	<i>Research on random point processes</i>	66
5	<i>Department of Econometrics</i>	67
5.1	<i>Economic Dynamics and Macroeconomic Modelling</i>	74
5.1.1	<i>Dynamic Models of Monetary Economy</i>	74
5.1.2	<i>Economic Model of Cycles</i>	75
5.2	<i>Cooperation Model and Fuzzy Set Approach</i>	75
5.3	<i>Stochastic Optimization</i>	76
5.3.1	<i>Stochastic Programming and Decision</i>	76
5.3.2	<i>Comparison of Multistage Stochastic Programs with Recourse and Stochastic Dynamic Pro- grams with Discrete Time</i>	77
5.3.3	<i>Variance Penalized Stochastic Optimization</i>	77
5.4	<i>Theoretical Finance</i>	78

5.4.1	<i>Consumption-based Capital Asset Pricing Model</i>	78
5.4.2	<i>Expectation Heterogeneity</i>	78
6	<i>Department of Pattern Recognition</i>	81
6.1	<i>Statistical Pattern Recognition</i>	86
6.2	<i>Method of Finite Mixtures</i>	86
6.3	<i>Probabilistic Neural Networks</i>	87
6.4	<i>Markov Random Fields</i>	88
7	<i>Department of Image Processing</i>	91
7.1	<i>A New Wavelet-Based Measure of Image Focus</i>	94
7.2	<i>Combined Blur and Affine Invariants</i>	97
7.3	<i>Application of image processing for the conservation of the medieval mosaic</i>	99
7.4	<i>Detection of additional manipulations in digital images</i>	102
8	<i>Department of Digital Signal Processing</i>	105
8.1	<i>Logarithmic Arithmetic Unit in FPGA</i>	113
8.2	<i>FPGA implementation of European Logarithmic Processor</i>	114
8.3	<i>Support for Simulink and RTW in Real-Time</i>	115
8.4	<i>Support for Czech an NAS Participation in EU Research Programmes</i>	116
8.5	<i>Notebook for the Blind</i>	117
	References	119

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- F. Matúš: Highly structured distributions in AI, cryptography and combinatorics. (Grant GA AV ČR No. A107 5104)
- J. Outrata: Variational problems in non-smooth mathematical physics: Theory, numerical methods and applications. (Grant GA AV ČR No. A107 5005)
- M. Studený: Conditional independence structures: Information-theoretical approach II. (Grant GA ČR No. 201/01/1482)

University Courses:

- Faculty of Mathematics and Physics of the Charles University
 - Markov distributions over graphs (F. Matúš)
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Prof. A. P. Dawid (University College London, GB)

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Most of the research activities of the department belong 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:

- mathematical optimization,
- differential equations,
- probabilistic decision support systems,
- artificial intelligence and alternative calculi.

1.1 Flow problems with incompressible fluids

In applications of incompressible fluid flow, it often occurs that flow is driven by a buoyancy force, i.e. in a gravity field warmer fluid is driven up while colder one falls down. It can be described by a system of equations for incompressible non-Newtonian (of the p -power type) viscous flow coupled with the heat equation. Such a system was considered in a smooth n -dimensional bounded domain, $n = 2$ or 3 , with heat sources allowed to have a natural L_1 -structure and, in some cases, even to be measures. In the evolutionary case, see [190], the existence of a distributional solution

was shown by a fixed-point technique for arbitrarily large data if p is greater than the spatial dimension, i.e. in a shear thickening case, and globally in time if adiabatic-heat effects dominate the dissipative heat. Some continuity properties of the temperature are established if the heat sources do not concentrate. In the steady-state case, see [204], the existence of a distributional solution was shown by a fixed-point technique for sufficiently small data if $p > 3/2$ (for $n = 2$) or if $p > 9/5$ (for $n = 3$), i.e. both shear thickening and shear thinning cases were admitted. Optimal control of such systems are currently studied within one diploma thesis.

1.2 Shape of elastic bodies in unilateral contact

We investigated a discretized version of the shape optimization problem for elastic bodies in contact with a rigid obstacle. The aim was to extend the existing results to the case of contact problems obeying the Coulomb friction law. Mathematical model of the Coulomb friction problem leads to a quasi-variational inequality. It is shown that for small coefficients of friction, the discretized problem with Coulomb friction has a unique solution and that this solution is Lipschitzian as a function of a control variable, describing the shape of the elastic body.

The shape optimization problem belongs to a class of so-called mathematical programs with equilibrium constraints (MPECs). The uniqueness of the equilibria for fixed controls enables us to apply the so-called implicit programming approach. Its main idea consists in minimization of a nonsmooth composite function generated by the objective and the (single-valued) control–state mapping. In this problem, however, the control–state mapping is much more

complicated than in most MPECs solved so far in the literature, and the generalization of the relevant results is by no means straightforward. Numerical examples illustrate the efficiency and reliability of the suggested approach.

1.3 Non-graphical and graphical descriptions of conditional independence

A non-graphical method of description of probabilistic conditional independence structures by means of integral vectors named *structural imsets* (see also 2000 activity report) was updated and newly presented in [222]; an outline was presented in [223]. Emphasis was put on a dual method of description of these structures which uses supermodular functions. The duality between both types of description was explained from the point of view of theory of formal concept analysis with help of the concept of Galois connections. Moreover, Markov equivalent structural imsets were characterized and the problem of representative choice within the class of equivalent structural imsets was dealt with.

A specific *inclusion problem*, that is the task to characterize in graphical terms the situation when one acyclic directed graph K induces a smaller conditional independence structure than the other acyclic directed graph L , was treated in [130, 129]. Several graphical characterizations were given in [130] and Meek's conjecture about transformational characterization of that situation in a special case when K and L differ in at most one adjacency was confirmed in [129].

1.4 Convex cores of measures

Let Q be a finite Borel measure on the Euclidean space R^d . Borel sets $B \subseteq R^d$ with the property $Q(B) = Q(R^d)$ are called full. The intersection of all closed and full sets is the *support* of Q and, similarly, the intersection of all closed, convex and full sets is the *convex support* of Q . The support of Q is closed and full and the convex support of Q , $cs(Q)$, is closed, convex and full. The intersection of all convex and full sets seems to have been unmentioned and was introduced under the name *convex core* of Q , $cc(Q)$, in the joint work [41] of Imre Csiszár and František Matúš. It is of primary importance for understanding closures of exponential families and problems involving I -divergence projections.

The set $cc(Q)$ is convex but not necessarily full, e.g. for the Lebesgue measure on the boundary of a ball, the convex core is the interior of the ball which has measure zero. Obviously, $cc(Q) \subseteq cs(Q)$ and we showed that $cs(Q)$ is the closure of $cc(Q)$. Points $x \in R^d$ that are of positive measure, $Q(x) > 0$, belong clearly to $cc(Q)$ and thus their convex hull is a Borel set contained in $cc(Q)$. If the support of Q is at most countable then $cc(Q)$ coincides with the convex hull of the support. In general, it is not obvious that $cc(Q)$ is a Borel set but we succeeded to prove that this is the case.

The convex core is closely related to the means of probability measures dominated by a given measure Q . The key result is that the set of these means is equal to $cc(Q)$. Convex cores of sums, products, images and convolutions of measures were investigated and relations of this work to some results of Chentsov (Statistical Decision Rules and Optimal Inference; Translations of Mathematical Monographs Amer. Math. Soc., Providence – Rhode Island 1982. Russian original: Nauka, Moskva, 1972) were clarified.

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Grants and Projects

- S. Čelíkovský, M. Šebek: Numerical algorithms for control and filtering (Grant Agency of the Czech Republic), No. 102/02/0709.
- J. Doležal, Prague Technology Center (Honeywell), Bilateral Agreement UTIA-Honeywell.

- V. Kučera, Robustesse et structure des systemes lineaires sur anneaux Joint Reserach Agreement CAS-CNRS, (CNRS France), No. CNRS-AVCR 5108.
- V. Kučera, Dynamic Control & Management Systems in Manufacturing Processes (European Community – Copernicus), No. CP97:7022.
- V. Kučera, Advanced Methodologies and Tools for Manufacturing Systems (European Community – Copernicus), No. CP96:0026.
- M. Šebek, Industrial Applications of Polynomial Methods (Czech–Japanesse project), No. NJ 11/98.
- M. Šebek, Convex Optimization and Polynomial Matrices in Control (Czech-French project – Barrande), No. 2001-031.
- M. Šebek, EUROPOLY – The European Network of Excellence for Industrial Applications of Polynomial Methods (European Community – Copernicus), No. CP97:7010.
- M. Šebek, Algorithms and Software for Analysis and Synthesis of Linear Multivariable Control Systems (Czech–Greek project), No. 12.
- S. Čelikovský, CONYCAT, México, Joint Research Project, No. 31 844-A.
- M. Šebek, Center for Applied Cybernetics, Min. Edu. CZ, No. LN 00B096.

Teaching Activities

- S. Čelikovský, Universidad Autonoma de Yucatan, Facultad de Matematicas: *Stabilization of Nonlinear Systems* (Minicourse, November-December 2001).

- D. Henrion, Universidad de los Andes, Merida, Venezuela: *Polynomial Methods in Robust Control* (Midicourse, October and November 2001).
 - 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 *Nonlinear Systems* (graduate).
-
- 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).
 - V. Kučera is *Chairman of the national jury for Doctor of Science research degrees in Engineering Cybernetics and Computer Engineering*.

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 Šála, SK; Czech Technical University, CZ; and University of Warsaw, P. The current list of EUROPOLY external members include Daimler-Chrysler, D; Duslo Šála, 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).

Our Visitors

- F. Kraus, ETH Zürich, CH,
- L. Mirkin, Tel Aviv University, Israel,
- H. Kwakernaak, University of Twente, Enschede, NL,
- L. M. Villagrán, Universidad De San Carlos De Guatemala, Guatemala,
- D. Henrion, LAAS-CNRS Toulouse, FR,
- V. N. Lyubenova, Institute of Centre and System Research, BAS, BG,
- T. Söderström, Department of Systems and Control, Uppsala University, S,
- J. J. Loiseau, CNRS LAAS de Nantes, F,
- A. G. Vardulakis, Aristotle University of Thessaloniki, Greece,
- N. Karampetakis, Aristotle University of Thessaloniki, Greece,
- J. L. Ruiz, CINVESTAV, I.P.N. Guadalajara, MX.

Representation in International Societies

- S. Čelikovský – IFAC-Vice-Chairman of Technical Committee on Nonlinear Systems;
- J. Doležal – President of the Czech Committee for IFIP and Full Member Representative in IFIP General Assembly;
- D. Henrion – Member of the Conference Editorial Board of the IEEE CSS;
- V. Kučera – President Elect of IFAC 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;
- Executive Committee member of the Czechoslovakia IEEE Section;
 - Executive Committee member of the Central European Chapter of the IEEE SME.
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Editorial Boards

- J. Ježek – Kybernetika;
- D. Henrion – IEEE Control Systems Society Conference Board;
- V. Kučera – Bulletin of the Polish Academy of Sciences;
- International Journal of Control;
 - International Journal of Robust and Non-linear Control;
 - International Journal of Systems Science;
 - Kybernetika.
- M. Šebek – European Journal of Control;
- D. Henrion – IEEE CSS Conference Editorial Board.

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 Linear Matrix Inequalities for Polynomial Matrices in Control

Following our research efforts of the previous years, we investigated further applications of convex optimization techniques to solve control problems involving polynomial matrices.

The use of Yakubovich's S-procedure allowed us to derive an ellipsoidal approximation of the set of stable polynomials in the coefficient space [70]. Application of this technique to robust design of systems affected by ellipsoidal uncertainty (an uncertainty model naturally arising in identification by least-squares methods) was proposed [73].

El Ghaoui's linearization scheme based on semidefinite programming complementarity conditions was applied to the difficult problem of static output feedback formulated with polynomial matrix fraction descriptions [68].

In addition, we developed a series of algorithms based on convex parametrization of positive polynomial matrices

along a one-dimensional curve. The new algorithms were used to solve various control problems without prior transformation into state-space. In particular, they handle direct computation of the H-infinity norm of a polynomial matrix fraction description [72], strictly positive real analysis and design with applications in adaptive and non-linear systems control. and, robust stability analysis and robust design with polytopic uncertainty.

A user-friendly interface was developed to powerful public domain software SeDuMi to solve linear matrix inequalities involving several hundreds of decision variables.

Besides this, simple algebraic techniques were used to show that the problem of simultaneous stabilization of a set of scalar systems (a notorious open robust control problem) can be solved easily provided static output feedback is used.

2.2 Pole Placement and H_2 Control

The H_2 optimal control problem consists in stabilizing a linear system in such a way that its transfer function attains a minimum norm in the Hardy space H_2 . Under slightly restrictive assumptions of reachability and observability, this problem was interpreted as a pole placement design [149]. As a result of this interpretation, a synthesis algorithm was obtained that is based on transfer function description in terms of polynomial matrix fractions. In fact, there is a dual version of this algorithm that is also presented. The optimal controller is obtained by solving one polynomial matrix equation, two matrix spectral factorizations, and three matrix fraction conversions.

The algorithm offers a computationally attractive alternative to the standard state space approach to the design of H_2 optimal control systems. Moreover, it can easily be

implemented using Polynomial Toolbox for Matlab. The experiments suggest that the proposed algorithm is to be preferred to the standard one whenever the system has many states and few inputs and outputs.

2.3 *The Matrix Completion Problem*

The Matrix Completion Problem was published three years ago as a challenge in Linear Algebra and Its Application. It consists in completing a given matrix pencil by other pencils to achieve a prescribed Kronecker invariants of the resulting pencil. The formulation covers many problems encountered in linear control theory such as invariant factors assignment.

In [157] an attempt has been done to solve, at least partially, this very difficult problem. Many results covering some interesting special cases have been established and discussed. This opens a way towards a general solution.

2.4 *Modules Over Noncommutative Rings for Nonlinear Systems with Delays*

Nonlinear systems with delays have got considerable attention recently. However efficient mathematical tools for their studying are not very well developed yet.

The paper [251] follows that line. A theory of modules over a ring of non-commutative polynomials (the indeterminate does not commute with coefficients) defined over the field of meromorphic functions is developed therein, and then it is used to characterize the concept of weak observability. A new class of nonlinear systems with delays, called Generalized Roesser Models, is also introduced. This class can be viewed as a generalization of Roesser models known in linear system theory.

2.5 Numerical Methods for Polynomial Matrices

Our long-term effort in developing better numerical algorithms for polynomial matrix operations used in control achieved another success. A brand new and really original method has been derived for computing spectral factors of scalar polynomials. The method is very fast as it is based of Fast Fourier algorithm. It is also very reliable and hence quite suitable for polynomials of extremely high degrees such as 1000 and more. The new routine has already been applied in acoustics where polynomials of such high degrees arise quite naturally. In particular, the new method enabled to upgrade the quality of loudspeakers by using a feedforward filter.

2.6 Controllability and Stabilizability of Nonlinear Systems

An interesting new class of single input nonlinear systems called "essentially triangular" was introduced and studied [36]. Although these systems exhibit a rather complicated structure, very interesting results were achieved. In particular, it was proven that small time local controllability of such a system implies its local asymptotic stabilizability via continuous static state feedback. It is well known that the results of this type are rather rare for nonlinear systems, where relation between controllability and stabilizability is not so straightforward as in the linear case. A detailed study of the new class of systems was published. The new theory has been successfully tested on a underactuated weakly coupled mechanical system.

2.7 Robust Output Regulation of Nonlinear Systems

The robust output regulation is a theoretical framework for a typical task in control engineering practice. It consists in tracking of a prescribed reference signal by the given system output while influence of undesired perturbations is rejected. Both the reference and the perturbations are generated by a known but uncontrolled exogeneous system. Robustness aspects are typically modeled via presence of uncertain parameter in the system model. Solution of the problem heavily depends on the feedback compensator used. The most useful in practical applications but, at the same time, the most difficult to design, is the error feedback dynamic compensator that operates on the error between desired and actual output only. To relax solvability conditions, it was first assumed that both error and the exostate measurements are available. Later on, only measurements of the error and certain output of the exosystem were used, using a suitable observation scheme to be combined with earlier results.

Necessary and sufficient solvability conditions were obtained for the above problem. The conditions were tested on illustrative examples, including some case studies and their computer simulations [35]. Moreover, for some special classes of systems, the classical error feedback problem was addressed, including design of that feedback via symbolic computer computations, see [237].

2.8 Output Feedback in Nonlinear Systems

The problem of detectability and dynamic output feedback control of the nonlinear systems were addressed and applied to some practical case studies. First of them is the water storing plant consisting of two cascade connected tanks, wa-

ter influx and two electromechanical valves controlling the outflux of the water from tanks. Designed controller used only measurements of water levels in tanks and were able to keep them on prescribed values despite unknown water influx into that cascade. The controller was based on nonlinear detection scheme combined with state stabilizability results. Another case study dealt with the waste water treatment plant cleaning waste using bacteria. Here, nonlinear detector combined with fuzzy controller enabled good performance regulation of cleaning effect despite unknown influx of polluted water. See [3,4,6] [208, 209, 37].

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Year 2001 was full of events. N. Khaylova submitted her thesis [120], PhD students K. Belda, L. He, P. Gebouský and V. Šmídl have progressed well, passed state exams and work towards their PhD thesis. New student M. Novák has started to address complex problem of pre-tuning of multivariate adaptive controllers. The undergraduate students J. Andryšek, J. Kracík and J. Strnad work on their diploma thesis and P. Němcová has become a senior representative among undergraduate students we are working with. M. Valečková left us, L. Pavelková is returning back from her maternity leave, R. Kytka helps us to manage hardware and software, RODOS team was supported by V. Hošťáková, and new experienced researcher J. Knížek joined us.

Generally, the Institute deals, among other topics, with analysis and design of systems generating predictions, making decisions or controlling other systems. Our Department inspects the systems that are able to modify their be-

haviour with the changing environment or operating conditions. This essential ability, called adaptivity, enhances the efficiency of the systems performing the mentioned tasks. During decades of systematic research we have reached significant conceptual, theoretical, algorithmic, software and application results. Our know how helps us in major projects like ProDaCTool or RODOS related activities. It is shared and enhanced further on within the framework of “Research and Education Centre in Adaptive Systems” (RECIAS) coordinated by AS department.

We try to extend the applicability of adaptive systems towards complex cases. It is done both by improving the classical adaptive systems and by inspecting new approaches to their construction. The interplay between theory and always limited computing power is the common issue hidden behind variety of particular projects we solve in radiation protection, transportation, management and control of technological systems, nuclear medicine etc.

A successful serie of workshops on the “curse of dimensionality” has been extended by an invited session at ICANN’01 conference [101].

Grants and Projects

Institutional state support forms our basic budget. The acknowledged support of firms Compureg Plzeň, s.r.o., Simone Research Group, s.r.o., Merit s.r.o. and Honeywell Prague Research Center makes us feel we are useful. The following list acknowledge the additional support from instituonalized sources.

- L. Bakule – *Robust decentralized control of large-scale systems* (GA AV ČR A2075802)
- K. Belda – *Solution of forward kinematics of redundant parallel robot for predictive control* (IG CTU 300104412)
- J. Böhm – *Algorithms and Implementation of Self-tuning Multivariate Controllers* (GA ČR 102/99/1292, successfully concluded)
- J. Böhm – *Redundant Parallel Robots and their Control* (GA ČR 101/99/0729, successfully concluded)
- T. V. Guy – *Hybrid Self-Tuning Controller* (GA ČR 102/00/P045)
- T. V. Guy – *Advanced Tools for Control and Monitoring of Complex Systems* (MŠMT ME 2001/020)
- L. Jirsa – *Solution of Modelling and Algorithmic Problems of Bayesian Estimation in Nuclear Medicine and Dosimetry of Ionising Radiation* (GA ČR 102/00/D072)
- M. Kárný – *Research and Education Centre in Adaptive Systems: pilot project* (GA ČR 102/99/1564, successfully concluded, RECiAS remains active)
- M. Kárný – *ProDaCTool – Decision Support Tool for Complex Industrial Processes Based on Probabilistic Data Clustering* (EC IST-99-12058)
- M. Kárný – *Identification of output error models for control design* (AV ČR S1075102)
- J. Knížek – *Design of a Computer Module for Information Analysis of Time Series of Autonomous Protein System Responses (MIAPS)* (IGA MZ ČR, 6458-3)
- F. Kraffer – *Geometric methods in algebraic theory implementation to multivariable systems* (EC, HPMF-CT-1999-00347, Individual Marie Curie Fellowship)
- R. Kulhavý – *Non-linear estimation and change detection of stochastic systems* (GA ČR 102/01/0021)

- P. Pecha – *Customisation of RODOS system for Czech Republic* (State Office for Nuclear Safety (SÚJB), contract no. 1042, successfully concluded)
- P. Pecha – *Localisation of the final version RODOS 4.0F for early phase of nuclear accident* (SÚJB, new contract no. 1044)

University Courses

Education is an integral part of the research. We are supervising a relatively high number of MSc. theses and undergraduate research projects. The students are also attracted by regular

(Under)graduate courses we give:

- Faculty of Physical and Nuclear Engineering, Czech Technical University (ČVUT)
Adaptive Control (M. Kárný)
- Faculty of Transportation, ČVUT
Course of Probability Theory and Statistics (I. Nagy)
- Faculty of Electrical Engineering, ČVUT
Predictive Control (J. Böhm)
CAD of Control Systems (P. Nedoma)
- Faculty of Mechanical Engineering, ČVUT
Tutorials from Mechanics (Statics, Kinematics, Dynamics) (K. Belda)

International dimension in teaching has been reached through the department activities in:

Central European Graduate School in Systems and Control Theory, (CEGS) established by ÚTIA together with the Czech Technical University, SZTAKI Institute of Hungarian Academy of Sciences and the West Bohemia University.

International Cooperation and Travels

International co-operation was driven predominantly by running projects and agreements of Academy of Sciences, CEGS and a Marie Curie Fellowship. Our major partners are in UK, Ireland, Spain, Slovakia, Slovenia, Hungary, Bulgaria, Ukraine and France. We hosted A. Quinn (IRL), K. Warwick, A. Kanouras, D. Parry, K. Darby, M. Taylor, R. Pattel (all UK), M. Ignatova (Bulgary), D. Vrančič, A. Rakar (both Slovenia), M. Alexik, A. Jaroš (both Slovakia), M. Barao (Spain) and G. Shederkenyi (Hungary).

International PhD workshop “Cybernetics and Informatics Eurodays: Young Generation Viewpoint” held in Balatofüred, Hungary, September 17–20, 2001 was organised by students and young researchers for their peers. This is a second event in a serie of interdisciplinary workshops that should help young people to build new contacts, present their research results, [18, 119]. Our students, supported by RECiAS, proved to be both active and successful participants.

Conference trips led to, mostly successful, presentations:

- L. Bakule, 9th IFAC/IFIP/IMACS/IFORS Symposium on Large Scale Systems, Bucharest, Romania, invited IPC member, invited session organizer, chairman of another session, and author [10]
- L. Bakule, WSES/IEEE International Conference on Simulation, Qawra, Malta, [11]
- J. Böhm, Process Control PC 2001, Štrbské pleso, [25]
- J. Böhm, ECC’01 , European Control Conference, 4-7 September, Porto, Portugal, [28]
- K. Belda, J. Böhm, N. Khaylova, IASTED International Conference “Modelling, Identification, Control” MIC 2001, Innsbruck, [19, 118]

- K. Belda, J. Böhm, Process Control PC 2001, Štrbské pleso, [26]
- K. Belda, Conference on Systems CSCC 2001, Rethymno, [27]
- K. Belda, N. Khaylova, M. Novák, The 2nd International Workshop "C&I Eurodays: Young Generation Viewpoint", Balatonfüred, Hungary, September 17-20, 2001, [18, 119]
- K. Belda, MATLAB 2001, Prague, [17]
- T.V. Guy, 5th International conference on Artificial Neural Nets and Genetic Algorithms, Prague, [55]
- F. Kraffer, 1st IFAC/IEEE Symposium on System Structure and Control, Prague, Invited Session on Diophantine Equations and Algebraic Design Approaches
- F. Kraffer, invited lecture, Amphi S, IRCCyN, CNRS UMR 6597, Nantes, France
- M. Kárný, Summer School MAP, Krajnska Gora, Slovenia, invited lecture "Bayesian dynamic decision making"
- V. Šmídl, 17th International Conference on Information Processing in Medical Imaging, Davis CA, USA, 18. – 22. June 2001, [217]
- P. Pecha, 7th International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes, Belgirate, Italy, May 28-31, 2001, [198]
- P. Pecha, ECORAD 2001 - International Congress on the Radioecology-Ecotoxicology of Estuarine and Continental Environments, Aix-en-Provence, Sept. 3 - 7, 2001, [199].

Long-term stays abroad of our members included:

- L. Bakule, Technical University, Barcelona, Spain, invited stay
- F. Kraffer, Institut de Recherche en Communications et Cybernétique de Nantes, CNRS UMR 6597, Individual Marie Curie Fellowship

- L. Jirsa, Trinity College Dublin, in connection with the project ProDaCTool, IST-99-12058
- L. Tesař, Trinity College Dublin, in connection with the project ProDaCTool, IST-99-12058
- V. Šmídl, Trinity College Dublin, in connection with the project ProDaCTool, IST-99-12058

Short-term stays abroad of our members included:

- L. Bakule, Technical University, Bucharest, Romania, invited trip, member - IFAC TC Large Scale Systems meeting
- J. Bůcha, Belgium, IST Information Days
- P. Gebouský, UK, Reading University, technical stay related to the project ProDaCTool, IST-99-12058
- T.V. Guy, Summer School MAP, Krajnska Gora, Slovenia, within the bilateral Czech-Slovenian project ME 2001/020
- M. Kárný, P. Nedoma, T.V. Guy, I. Nagy, IRL, Trinity College Dublin, technical and coordination meeting of the project ProDaCTool, IST-99-12058
- M. Kárný, UK, Reading University, coordination meeting of the project ProDaCTool, IST-99-12058

RESULTS

3.1 ProDaCTool: Operator Support

Complex processes like rolling mill, transportation system, medical diagnostic system etc. offer to the operator a lot of data to be used for an efficient maintenance. Its quality depends heavily on the operator skills. Thus, it is desirable to provide him with an advisory system. The advisory system designed within ProDaCTool relies on the following simple idea. Differences in operation quality are expected to manifest themselves in different modes of the distribution of the observed data. This distribution is approximated

by a high dimensional mixture of unimodal – dynamically positioned – distributions called components. Distances of components to a target distribution describing management aims are evaluated. Univariate cross-sections of the components nearest to the target distribution are presented as advises to the operator.

The substantial progress has been made in the year 2001. Among others, the decisive problem of initiation of mixture estimation of has been solved [5, 116], numerically stable version of a standard mixture estimation technique used for benchmarking was designed and extended to dynamic mixtures [189]. Learning of Markov factors [138], dynamic factors with coloured noise [62, 47, 55, 54] and a specific use of mixtures for sparsely parameterized Markov chain models [234] were addressed as specific sub-problems.

The design part of the advisory system gradually reaches its applicability stage. It led to rigorous quadratic optimal design for systems described by dynamic mixture models [28] and opened the way to the first application in nuclear-medicine diagnostics [100].

3.2 Model validation in high dimensions

A serious general problem emerged in connection with high-dimensional mixture estimation: “How to validate the resulting model in a feasible and reliable way?”.

Visual comparison of estimated clusters and data, or corresponding prediction errors in dynamic case, can play auxiliary role only in the considered high dimensions. The v-likelihood, i.e. likelihood evaluated for specific model variants, proved to be the adequate tool. Formally, the v-likelihood is defined by the formula $L(S, f(\cdot|S)) = \int_{\Theta} f(D|\Theta, S)f(\Theta|S)d\Theta$ where D is the measured data sam-

ple, Θ is a vector of model parameters, S denotes model structure used including its prior setting and f is a common symbol for probability (density) function. Suitable choice of compared variants decides on the validation efficiency. The following variants look promising.

Comparison of piece-wise and batch estimation. The data sample is split into two parts and the estimation runs separately on the first part, the second part and the whole data set. Denoting the corresponding v-likelihoods by L_1 , L_2 and L , the good estimation should lead to $L > L_1L_2$.

Testing by stabilized forgetting. The validated model is taken as so-called alternative model, reflecting “sure” information, in estimation with a stabilized forgetting. The contribution of the additional data processing to the “sure” alternative model is judged by comparing v-likelihoods of models resulting from estimation with different forgetting factors. The model is taken as a validated one if the smallest forgetting factors wins: the additional processing brings nothing to the estimated model.

3.3 Non-linear estimation and change detection of stochastic systems

The work continued on development of new methods of intelligent data analysis based on Bayesian smoothing.

- A connection between kernel methods of nonparametric regression and Bayesian estimation of local model parameters with special smoothness priors was shown and analysed with the objective to improve tuning of the model hyperparameters.
- A new method of abnormal event detection was proposed based on estimating the amount of information in the new data measured by Kerridge innaccuracy. The method needs

to consult only historical data close/similar to the new data and can be regarded as an application of local modelling in fault detection.

- Applications of local modelling to effective decision support were studied and published (Chemical Process Control Conference, American Control Conference).
- Research continued on understanding the connections between Bayesian smoothing and information geometry. This work resulted in invitation to the 2002 NATO ASI on Learning Theory and Practice (<http://www.esat.kuleuven.ac.be/sista/natoasi/ltp2002.html>).

3.4 Computer-Aided Design of Adaptive Controllers

Development of adaptive controllers continued in several directions:

Elaboration of algorithms and software and their testing. The single-input, single-output version of the computer-aided design of adaptive controllers (DESIGNER) was extensively tested. The tests stimulated significant improvements in algorithmic use of prior knowledge [120]. A further systematic software development turns gradually to the object oriented design. New approaches to such design were continually studied, a new tool (Rational SoDA) has been tested and the use of previously introduced tool (Rational Rose) was extended.

An attempt to use DESIGNER for control of yeast production was successful. Estimation and control design were made using real data measured on the process of fermentation in bioreactor. The good quality of the automatically designed controller was verified on the precise non-linear SIMULINK model of the process. The results of the ex-

periment confirmed that the gained controller met the control aims while respecting the given constraints [90]. The non-expert in adaptive control obtained these results in a couple of days. It indicates reachability of the basic aim of DESIGNER: to decrease the commission time as well as the expertise level needed.

This application will be elaborated further on in cooperation with Institute of Control and System Research, Bulgarian Academy of Sciences.

Algorithmic development. Multi-input multi-output version of the computer aided design was addressed by searching for efficient techniques of selecting penalisation weights so that constraints on involved signals are respected. Report [191] shows successful results of this development. The initialization of the constrained optimization and the computational speed call for further improvements.

Advances in the control design. Robustness properties of the multi-model linear quadratic (LQ) synthesis were further investigated [25]. The formalized design of a controller for a system described by a mixture model [28] led to similar results.

New options enriched the multivariate LQ adaptive controllers so that practical requirements are met more easily. They guarantee smooth startup of the controller, eliminate offset in a step response and support the design of the LQ controller connected in parallel with another fixed controller.

Control application in robotics. The integrator saturation is a main problem in a control of redundant parallel robots with decentralized control. This problems was solved by the extracting useful part from the generated moments. The remaining “unproductive” part is further used to eliminate the saturation of integrators. Forward kinematics was derived

and used for the control of platform coordinates in case when only drives angles (velocities) are available for measurement. The redundancy was used to derive an antibacklash control fulfilling the condition that all moments over the trajectory do not change the sign [27].

3.5 Robust Decentralized Control of Large-Scale Systems

Theory. New results have been achieved within the Inclusion Principle for various classes of dynamical systems. Both continuous-time linear time-varying systems (LTV) [15] and discrete-time LTV systems [10], [14] are considered. The results concern an extension of the generalized selection of complementary matrices, which has been originally developed for linear time-invariant systems, to above mentioned classes of dynamic systems. While these results hold only for a commutative class of continuous-time LTV systems, they hold generally for discrete-time LTV systems. The emphasis has been put on quadratic optimal control for discrete-time LTV systems in [10] and guaranteed cost control for uncertain, nominally linear, discrete-time LTV systems in [14]. Uncertain systems consider parameter norm-bounded time-varying uncertainty both in state and input matrices. Derivation of explicit block structured conditions on complementary matrices of systems and controllers within the expansion-expansion scheme is the main contribution in all these cases. Moreover, particular selection procedures for complementary matrices and numerical examples have been supplied.

Decentralized control of large-scale mechanical structures.

Two different decentralized control design strategies have been proposed, evaluated and reported for the first gener-

ation of benchmark structural control design problem for the cable-stayed bridge. The bridge is currently under construction in Missouri, USA. It consists of two towers, has a total length 1.2 km, and the construction has 128 cables. A three-dimensional evaluation model has been developed to model complex behavior of the full scale bridge. The overall finite element model consists of 838 states. The goal is to propose active control design strategy including selection, locations and models of sensors, actuators, and control design algorithms, which will effectively protect the bridge against earthquake excitations. There are available 18 evaluation criteria which must be simultaneously satisfied in an acceptable way. They include also critical cable tensions. The disjoint type decentralized control strategy [6] and overlapping decentralized control strategy [7] have been proposed, verified by simulations, and evaluated. Both proposed strategies succeeded. The advantages of these approaches are in the possibility of parallel real-time implementation of local controllers, reduction of transmission costs in the feedback loop, and in increase of operational reliability of controllers.

Both discussed approaches represent a new promising direction in structural control, which combines the most recent knowledge in advanced theory of decentralized control, structural engineering, complex systems modelling, and simulation. The results have been achieved within long-term, international, and multidisciplinary intensive cooperation.

3.6 Robust Control of Multivariable Systems

In view of developing new and successful techniques for targeting polynomial matrix equations, both linear and quadratic, connections between various results in the geo-

metric and algebraic approaches to control system design have been studied [139], [141].

The equation $X_l D_r + Y_l N_r = D_k$ was reviewed in order to pinpoint and get all polynomial matrix solution pairs (X_l, Y_l) generating proper polynomial matrix fractions $C = X_l^{-1} Y_l$ whose denominator is row-reduced with a priori prescribed (sufficiently large) row degrees [143], [145]. The result is important for the design of proper compensators in a unity closed loop with a strictly proper plant.

The equation $B(s) = A^*(s)A(s)$ was addressed for application in canonical spectral factorization of a diagonally-reduced para-Hermitian matrix which is either positive definite or positive semidefinite on the imaginary axis. A novel and less computationally expensive iterative solution was derived, which restricts to the lower-degree terms and avoids execution of elementary polynomial matrix operations. The result is important for quadratic filtering and control.

3.7 Continuous-time modelling and hybrid adaptive control

Continuous-time modelling based on a functional expansion is expected to bring a new quality that can improve both prediction and control quality. Various attempts are made in this direction.

Spline-based model of traffic systems. The splines approximation enhancing potential of mixture models has been successfully applied to the modelling of the traffic flow intensity. The traffic system was described by a static mixture model with time-dependent offsets approximated by the first order spline functions. An extended ProDaCTool package Mix-Tools has been used for identification. The experiments on real data – intensities of the traffic flow measured in Strahov tunnel in Prague – gave typical courses of the daily intensity

curve, corresponding to different day periods.

Hybrid adaptive controllers. These controllers respect explicitly continuous time in which the controlled system lives. The model they use is represented by combination of a convolution modelling of continuous time stochastic controlled system and spline approximation of involved signals, implemented as filtering. The LQ synthesis, employing continuous time quadratic criterion, works on approximated values of signals. Comparing to the traditional solutions, the obtained low order models guarantee a high control quality. The attempt to solve problem of smoothing at the grid intervals [54] has been made.

Wavelet-based modelling. The wavelet modelling uses filter banks to approximate input/output signals [56]. The multiresolution approximations of the signals are then used in the system description. Probabilistic interpretation allows us to use Bayesian approach to structure selection and offers an algorithm for the decision on the structure of multiple models obtained [55].

3.8 Integration of all Cognitive Functions

The curse of dimensionality implies that the predominantly algorithmic solutions of decision-making problems have to co-operate with knowledge-based approaches. These approaches are nowadays well developed, however, the machine learning creating the knowledge is still oriented on relatively simple systems [29]. Real applications deals, however, with complex systems. This made us to address learning suitable for them. The basic characteristics of the proposed framework were:

1)The machine learning is inspected in a broad context of a

problem solver (PS).

2) PS is integrating all cognitive functions.

3) PS is self-reflective.

4) Knowledge is applied to the design of learning itself. It is gained in the areas of artificial intelligence, machine learning, computer science, control engineering etc.

5) Object-oriented technology, computer aided software engineering approaches and tools, Unified Modeling Language, uncertainty and inconsistency processing, etc. are used.

In year 2001, we started to build a computer model of the framework. We use and integrate the object-oriented design tools, Smalltalk Visual Works non-commercial programming environment, and Prolog-like system Quasiquoted Smalltalk Open Unification Language. The experiments are done within a simulated chess environment.

3.9 Customisation of the RODOS system for ČR

Customised EU software product RODOS (Real time Online DecisiOn Suport) is a comprehensive decision support tool for nuclear emergency management. The localisation of the product for conditions of the Czech Republic consists of the adaptation of various models, local data collection, their pre-processing and import into RODOS database as well as quality assurance of the system. Translation of panels into the Czech language and creation of a proper map background for the sites of nuclear power plants (NPP) Dukovany and Temelín were necessary customization steps made in 2001. Also, the latest version 4.0F of the RODOS system was installed at State Office for Nuclear Safety (SONS) on a new workstation dedicated to routine use. Customisation according to the SONS demands continues.

The main research effort in 2001 has been concentrated on the atmospheric modelling and application of various counter-measures in the early phase of nuclear accident. New activities related to the forest and hydrological modules have been started and the first results are published in [195]. A collection of data for the modules having local character for the particular NPPs in ČR, their pre-processing and integration into RODOS are in progress.

In connection with the RODOS project, methodology and software tools for a partial evaluation of the radiological impact on population – caused by both accidental and routine atmospheric radioactive releases – are examined in [197]. A former comparison of various codes was extended in the [198]. The compliance of the RODOS design with the governmental regulations fixed in the Czech Atomic Law has been checked.

The generation of the radiological data for purposes of Environmental Impact Assessment analysis is described in [199]. A spatial distribution of near-ground activity concentrations in air and deposition rates are calculated. The results were submitted for the further EIA evaluation process according to the latest US EPA regulations.

3.10 Estimation Tasks in Nuclear Medicine

Bayesian methodology was used for reliable estimation of various quantities met in nuclear medicine, mostly describing the dynamics of accumulation/elimination of ^{131}I .

Non-traditional ways of accumulation/elimination modelling and improved measurement strategy brought a novel view on some formerly observed discrepancies between diagnostic and therapy evaluations [80, 81]. They significantly contribute to a widely discussed “stunning effect”, i.e. hy-

pothesis that the adopted diagnostic techniques influence substantially biological properties of the inspected tissue.

At the same time, the results serve directly to practice and they are being implemented in the routinely used software system *JODNEW*. English version of this software, called Iodine III, has been created that uses results of Bayesian estimation in connection with the internationally established Medical Internal Radiation Dose methodology. Moreover, advising on the administered therapeutic activity is tested in this version. It relies on methodology developed within Productool project.

Bayesian methodology helped us to extend principal component analysis (PCA) of dynamic medical image data to Smoothed PCA. The extension is based on inclusion prior information about smoothness of biological processes into PCA [216]. Various ways of quantification of this prior information were tried and evaluated. The advanced versions proved their efficiency on real-life data. Improvements brought by SPCA in comparison with PCA were the most pronounced on brain-image studies [217].

3.11 *MIAPS – Design of a Computer Module for Information Analysis of Time Series of Autonomous Protein System Responses*

Proteome analysis is one of the most intensively developing basic research branches in biological and experimental medicine. Its expected diagnostic potential is enormous. Gel electrophoresis is the predominantly used experimental method. It provides a lot of two-dimensional short time-series that should be quantitatively compared.

A novel statistical comparison of optical protein density time series was suggested. This method of detection of the

most usable proteins can serve as a predictor of potential pharmaceutical agents or their compounds.

Technically, the method fits Gram's polynomial regressions to the data and uses a statistical test polynomials' equality. The more the tested polynomial fails in the test the more useful information is expected to bear. A standard test is used to judge equality of a part of linear regression coefficients to a constant vector. A similar test is applied to linear combinations of the regression coefficients. Heteroscedasticity and autocorrelation is generally respected both for Gram's orthogonal polynomial identification and for a model of linear regression equation system.

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Jiří Michálek – analytical methods in stochastics,
random processes, statistical infer-
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- Jan Šindelář – theory of complexity and its application in probability and statistics, alternative theories of data processing
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- Petr Tichavský – system and signal theory, in particular sinusoidal modelling and high-resolution spectral analysis
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- Igor Vajda – information theory, mathematical statistics
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- Jan Ámos Víšek – robust statistics and econometrics, regression analysis, adaptive statistical methods, statistical computations, applications in economy and medicine
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- Petr Volf – survival analysis, nonparametric regression, smoothing methods, statistical reliability testing
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- Karel Vrbenský – computer science, optimal statistical algorithms
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Postgraduate Students:

- Lucie Fajfrová – probability theory, interacting particle systems
- Lucie Fialová – applied information theory
- Jaroslav Franěk – information theory
- Tomáš Hobza – nonparametric density estimation and applications in communication networks
- Martina Orsáková – regression analysis
- Martina Pavlicová – spectral theory of random processes

Conferences:

13 lectures, 2 of them invited, have been delivered at international conferences, including

Spatial Statistics, Statistical Physics, 2nd Conference, Wuppertal

Inverse Problems, Workshop, University of Aalborg

IXth International Conference on Stochastic Programming, Berlin

PRASTAN, Mathematical Statistics and Numerical Mathematics, Kočovce

ASMDA 2001 – Applied Stochastic Models and Data Analysis, Compiègne

SPA 2001 – Stochastic Processes and Applications, Cambridge (P. Volf, M. Janžura)

MME 2001 – International Conference Mathematical Methods in Economics (P. Lachout, J. Michálek, P. Volf)

23th EMS, Madeira

Applications of Information Theory, The European
Banach Center for Mathematical Sciences, Warsaw
(I. Vajda, M. Janžura)

International Workshop on Quantile Regression, Liberec

Grants and Projects:

- V. Beneš: “Integral geometry and statistics of random set components” (GA ČR, 201/99/0269, 1999 – 2001)
- M. Janžura: “Stochastic models of phase transitions in large interacting systems”
(GA ČR, 201/00/1149, 2000 – 2002)
- J. Michálek: “Robust statistics methods in time series exponential smoothing”
(GA ČR, 402/01,1548, 2001 – 2003)
- J. Šindelář: “Design of a computer Module for Information Analysis of time series of autonomous Protein System responses (MIAPS)” (IGA MZ ČR, 6458-3, 2001 – 2003)
- I. Vajda: “Optimization and estimation in communication networks” (GA ČR, 102/99/1137, 1999 – 2001)
- I. Vajda: “General asymptotic theory of M -estimates” (GA AV ČR, A 1075101, 2001 – 2003).

International Cooperation

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

- Aalborg, Denmark (Prof. J. Moeller, Prof. R. Waagepetersen)
- Atlanta, USA (Prof. A. M. Gokhale)
- Amsterdam, The Netherlands (Prof. B. van Es)
- Marburg, Germany (Prof. J. Steinebach)
- Vilnius, Lithuania (Prof. V. Paulauskas, Prof. M. Bloznelis)
- Ilmenau, Germany (Prof. S. Vogel, Prof. E. Liebscher, Prof. O. Gersch)
- Rostock, Germany (Prof. F. Liese)
- Madrid, Spain (Prof. L. Pardo, Prof. M. Menédez)
- Leuven, Belgium (Prof. E. van der Meulen, Prof. A. Beirlant)
- Montpellier, France (Prof. A. Berlinet)
- Baltimore, USA (Prof. J. Smid, Prof. A. Rukhin)
- Budapest, Hungary (Prof. L. Györfi)
- Hong Kong, China (now Waterloo, Canada), (Prof. K. T. Wong)
- Alicante, Spain (Prof. D. Morales)
- Ulm, Germany (Prof. W. Stummer)
- Copenhagen, Denmark (Prof. F. Tøpsoe)

The results of this cooperation are summarized in 11 published papers.

University Courses

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

University of Economics:

Informatics (P. Boček)

Charles University — Faculty of Mathematics and Physics:

Spatial Statistics, Monte Carlo Markov Chain Methods (V. Beneš); Mathematical Statistics, Design of Industrial Experiments, Sequential and Bayesian Methods (M. Hušková); Probability Theory (M. Janžura); Tutorial Lecture on Probability Theory, Advanced Parts of Econometrics (P. Lachout); Applications of Statistical Methods in Real Projects (J. Á. Víšek)

Charles University — Faculty of Social Sciences:

Mathematical Statistics (M. Hušková).

Czech Technical University — Faculty of Physical and Nuclear Engineering:

Stochastic Systems (M. Janžura); Quality Control (J. Michálek); Information Theory (I. Vajda); Modern Approaches to Data Processing (J. Á. Víšek).

Technical University Liberec:

Mathematical Statistics, Probability Theory and Mathematical Statistics (P. Volf).

The School of Professional Higher Education Chotěboř:

Elements of Mathematical Statistics (J. Michálek)

I. Vajda was a chairman of the State Examination Committee at 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, Faculty of Mathematics and Physics (Faculty of Social Sciences) and Czech Technical University.

Research Activities

The Department concentrates on mathematical research in the following areas.

- a) Information in statistical experiments and optimal statistical decisions (estimation, testing, classification), with emphasis on maximum entropy, minimum divergence methods, and asymptotic theory.
- b) Robust statistical procedures and their applications in various statistical environments, including adaptivity and self-organization. Regression analysis.
- c) Statistical inference in random processes and random fields. Applications in stochastic optimization, change-point, optimum investment portfolios, and image and speech processing.

Altogether 32 papers have appeared during 2001.

Recent Results

4.1 Bayesian analysis of log Gaussian Cox processes for disease mapping

We consider a data set of locations where people in Central Bohemia have been infected by tick-borne encephalitis, and

where population census data and covariates concerning vegetation and altitude are available. The aims are to estimate the risk map of the disease and to study the dependence of the risk on the covariates. Instead of using the common area level approaches we consider a Bayesian analysis for a log Gaussian Cox point process with covariates. Posterior characteristics for a discretized version of the log Gaussian Cox process are computed using Markov chain Monte Carlo methods. A particular problem is to determine a model for the population intensity, and the dependence of the results on the model for the background population intensity is discussed in detail. Model validation is based on the posterior predictive distribution of various summary statistics.

4.2 Computer module for simulation of communication network traffic

A new program to simulate real traffic of a communication network was developed. The network is based on models mentioned in prior publications of the department. All the results were processed statistically and compared with the computed values from the theoretical models. The simulations confirmed expected results – that means the theoretical model matches the real network.

4.3 Problems of estimating capability indices in SPC

When a process producing some products is controlled by quality control charts like Shewhart's ones the corresponding inherent variability (i.e. variability within subgroups) is usually estimated by sample range R or sample standard deviation s . Their averages \bar{R} or \bar{s} are then substituted into formulas for indices C_p or C_{ph} instead of unknown level

of inherent variability. The obtained estimates \hat{C}_p or \hat{C}_{ph} are random variables their distribution functions are difficult to express explicitly for a finite number of observations therefore their asymptotic behaviour of \hat{C}_p and \hat{C}_{ph} were described and studied.

4.4 Filtering, predictive, and smoothing Cramér–Rao bounds for discrete-time nonlinear dynamic systems

Quality evaluation of the nonlinear filters is one of the most complex problems in the area of nonlinear estimation. A lower bound for the mean-square error of an estimate can give an indication of estimator performance limitations and consequently it can be used to determine whether imposed performance requirements are realistic or not.

As is well known, the Cramér–Rao (CR) bound, defined as the inverse of the Fisher information matrix, represents an objective lower limit of cognizability of parameters in constant parameter estimation. The CR bound methodology was extended for random parameters estimation by Van Trees (1968). The idea of the CR bound was successfully applied in state estimation for discrete-time nonlinear stochastic dynamic systems by Bobrovsky & Zakai (1975) and Galdos (1980) and recently in Tichavský, Muravchik & Nehorai (1998). In the latest paper, the CR bound is computed using the idea to regard the state history as a random parameter vector. This new approach also allows to treat various singular cases (e.g. the case of nonlinear system with unknown constant parameters which will be shown in this paper) that frequently occur but could not be solved by the former approach.

As extension of the previous results, we derived structurally unified recursive relations for filtering, predictive,

and smoothing CR bounds and to extend these relations to a more complicated, but important case of a nonlinear stochastic system with unknown parameters.

4.5 *Nonparametric statistical information theory*

Applications of information-theoretic and statistical divergences and disparities have been studied in the areas of nonparametric distribution estimation and testing. Former results about asymptotic properties of the chi-square divergence errors of the Barron density estimator have been substantially refined in [233]. These refined results have been used to optimize the quantization sizes and reference densities in this estimator, and verified by extensive simulation studies. These results have been included in [233] and reported on the European Meeting of Statisticians in [233]. New asymptotic results concerning the whole family of divergence and disparity errors have been reported in [231] and submitted for publication in Transactions of IEEE. A new density estimator has been proposed, and its asymptotic properties and optimization studied in [23]. A new explanation of the famous Newcomb–Benford law governing numerical data sources has been found in [83]. New limit laws for divergence and disparity statistics were derived in [57].

4.6 *Parametric statistical information theory*

Paper [179] studied minimum divergence point estimators in continuous parametric models based on data quantized into a fixed number of cells. Asymptotic distribution of these estimators has been found and the loss of efficiency with respect to what is achievable in the original continuous mo-

del has been evaluated. Optimal quantizations minimizing this loss have been found and the rate of convergence of the minimal loss to zero with the number of cells increasing to infinity has been studied. These results have been refined and extended to the wider class of minimum disparity estimators in [180]. In [178] we evaluated and/or approximated the distributions of parametric disparity-based goodness-of-fit tests of hypotheses under local alternatives.

4.7 Prognosis and optimization in data networks

A queuing network model was proposed in [24], predicting the steady-state parameters of message handling telecommunication networks with a hierarchic topology (Jackson-type networks). A recursive algorithm has been found, able to evaluate these parameters in a reasonable time for networks consisting of hundreds of servers. Realization and verification of this algorithm on a PC computer has been reported, as its application on a fictive HYPERMARKET network consisting of 34 servers has been illustrated. The parameters evaluated by the model enable to optimize the projection of new networks and the management of the existing ones. The accuracy of the parameters predicted by the model has been studied by extensive simulations in 2001 using the module reported in part 1.2. This accuracy is surprisingly good if the network load is well below the capacity, but deteriorates as this load approaches or exceeds the capacity.

4.8 Consistency of the least weighted squares estimator

A consistency of the least weighted squares estimator were derived. The method differs from the classic weighted least squares in the same way as the method of the least trimmed

squares from the method of the trimmed least squares. The later has a priori (usually according to some external rule) assigned weights to the observations while the former assigns the weights implicitly, during the search for the solution of the corresponding extremal problem.

4.9 Research on random point processes

In the framework of the probabilistic models and statistical methods of survival analysis, the aggregated, grouped and categorized data observed in discrete time periods were considered. As an example, a real unemployment data were analyzed. The data contained a periodical information on the changes of the number of unemployed, and on the structure of the set of covariates (age, region, qualification, length of unemployment, season). The variant of proportional hazard (Cox's) model was used, with time-varying parameters. The test of their statistical significance was developed. The interactions of covariates were considered, too [244].

Further, the models and methods of statistical analysis of the cumulative process (compound sums driven by a counting process) were studied. The heterogeneity of the process' intensities was analysed, the estimates of the heterogeneity parameters were proposed and corresponding probability distribution estimated. The method was used for the detection of atypical trajectories of processes.

5 Department of Econometrics

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Jiří Hlaváček – Generalized decision-making
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Vlasta Kaňková – Stochastic programming,
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Jan Kodera – Nonlinear economic systems.
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Magda Komorníková – Fuzzy sets theory,
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Lukáš Vácha

Research Interest Fields:

- stochastic economics, and econometrics, and econometric modelling,
- theoretical fuzzy set approach to decision making,
- stochastic differential – difference equations and its applications to the mathematical finance,
- stochastic optimization,
- uncertainty processing in expert systems.

Grants and Project:

- V. Kaňková: *Development and Decision under Uncertainty in Economic Time Dependent Systems* (Grant GA ČR No. 402/01/0539)

- M. Mareš: *Mathematics, Informatics and Cybernetics: Tools and Applications* (Key Project of the Academy of Sciences of the Czech Republic No. K 1019101)
- M. Mareš: *Fuzzy Set Theoretical Approach to the Optimization Decision Making in Financial and Investment Policy* (Grant GA ČR No. 402/99/0032)
- M. Mareš: *Domination and von Neumann Solution in Fuzzy Coalitional Games* (Grant GA AV ČR No. A 1075106)
- K. Sladký: *Dynamic Models under Uncertainty in Economics and Finance* (Grant GA ČR No. 402/99/1136)
- M. Vošvrda: *The Rate of Asset Return Dynamics. Application for the Czech Republic* (Grant GA ČR No. 402/00/0439)
- M. Vošvrda: *Generalized Decision – Making Procedures* (Grant GA ČR No. 402/01/0034)

University Courses:

- *University of Economics, Prague:*
 - J. Kodera - Capital Markets
- *Charles University, Faculty of Social Sciences :*
 - A. Derviz - International Finance
 - J. Hlaváček - Advanced Microeconomics
 - V. Kaňková - Decision in Economics - Deterministic and Stochastic Optimization
 - M. Mareš - Game-like Behaviour in Economic Situation

- K. Sladký - Stochastic Processes with Economic Applications
- M. Vošvrda - Economic Dynamics
- M. Vošvrda - Economic Cycles Theory (SOKRATES)
- M. Vošvrda - Capital Markets Theory
- *Czech Technical University, Faculty of Electrical Engineering:*
 - M. Mareš - Coalitional Games Theory

Guests and visitors:

- Prof. Janusz Kacprzyk (Institute of System Research, Polish Ac. Sci., Poland)
- Prof. Dr. Miloš Duchoň (Mathematical Institute of the Ac. Sci., Slovakia)
- Prof. David Morton (University of Texas at Austin, USA)
- Prof. Silvia Vogel (Technical University Ilmenau, Germany)
- Dr. Eckhard Liebscher (Technical University Ilmenau, Germany)
- Dipl. Math. Oliver Gersch (Technical University Ilmenau, Germany)
- Prof. Dr. Nico M. van Dijk (University of Amsterdam, The Netherlands)
- Prof. D.S.G. Pollock (Queen Mary Collage, University of London, Great Britain)

Diploma and Doctoral projects

Diploma

- Faculty of Mathematics and Physics, Charles University (supervisor V. Kaňková - 1, M. Vošvrda - 3)

Doctoral

- Faculty of Mathematics and Physics, Charles University (supervisor V. Kaňková - 2, K. Sladký - 1)
- Charles University, Faculty of Social Sciences (supervisor M. Vošvrda - 6, (Plešinger successfully defended - PhD.))

Conferences – Participation

1. 2nd CeNDEF Workshop on Economic Dynamics, Amsterdam, January 2001 (Vošvrda)
2. GAMM – Workshop: Stochastische Modelle und Steuerung. Lutherstadt Wittenberg (Germany), April 2001 (Kaňková)
3. European Financial Management Association Annual Congress, Lugano, (Switzerland), June 2001 (Derviz)
4. 7th International Conf. on Computing in Economics and Finance, Yale University, June – July 2001 (Vošvrda)
5. EURO 2001: European Operational Research Conference, Rotterdam (The Netherlands), July 2001 (Kaňková, Sladký)
6. 17th International Conference on CAD/CAM, Robotics and Factories of the Future, Durban-South Africa, July 2001 (Kodera)

7. 9th International Conference on Stochastic Programming, Berlin, August 2001 (Kaňková, Šmíd)
8. 19th International Conference on Mathematical Methods in Economy 2001, Hradec Králové, September 2001 (Kaňková, Sladký, Vošvrda)
9. Eusflat 2001, Leicester, September 2001 (Mareš, Mesiar)
10. Uncertainty Modelling 2001, Bratislava, September 2001 (Mareš, Mesiar, Komorníková)
11. 4th Czech-Japan Seminar on Data Analysis, Jindřichův Hradec, September 2001 (Mareš)
12. Workshop: Risk and Dynamics, Prague, September 2001 (Kaňková, Sladký)
13. Exchange Rate Workshop, London, September 2001 (Derviz)
14. International Conf. NOSTRADAMUS, Zlín, October 2001 (Vošvrda)
15. Fall Econometric Day, Prague, November 2001 (Kaňková, Kódera, Sladký, Vošvrda)
16. AGOP 2001, Oviedo, July 2001 (Mesiar)
17. 9th Fuzzy Colloquium, Zittau, September 2001 (Mesiar)
18. 6th International Conference on Global Business and Economics, Bratislava, (Komorníková)

International Cooperations

Joint venture research group with University of Amsterdam (Department of Economic Sciences and Econometrics), JAIST (Japan), University of Gent (Belgium), Escola Superior de Technologia, Castelo Branco, Portugal, Technical University Ilmenau (Germany), JKU Linz (Seminar), University Alcala de Henares, University of Novi Sad, University La Sapienza Rome, University of Paris, University of Salerno and Artificial Intelligence Research Institute IIIA – CSIC, Bellaterra, Barcelona.

A cooperation for the macroeconomic model constructed for the Slovak Republic and for the Czech Republic continued with the Institute of Slovak and World Economics of Slovak Academy of Sciences, Bratislava.

Public Utility Services

Three members of the Department (V.Kaňková, J. Kodera, and M. Vošvrda), were elected in the Czech Econometric Society Board and Executive committee, K. Sladký was elected in the Czech Society of Operations Research Board.

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

M. Mareš was chairman of Czech association for the Club of Rome, Treasurer of the Czech Society for Cybernetics and Informatics and member of the American Mathematical Society, member of the European Academy of Sciences and Arts, member of the European Society for Fuzzy Logic and Technologies, Editor-in-chief of journal *Kybernetika*, member of Boards of the research programmes INFRA. Chair-

man of the 1st Commission for Evaluation of Research Plans of the Czech Universities with the Ministry of Education.

K. Sladký is Managing Editor of journal *Kybernetika*.

J. Kodera and K. Sladký are members of the Economic Sciences Division of the Grant Agency of the Czech Republic.

V. Kaňková and M. Vošvrda, were elected members of the Grant Agency of the Academy of Sciences of the Czech Republic.

R. Mesiar is member of Editorial Board of the International Journal *Fuzzy Sets and Systems*.

Results

5.1 Economic Dynamics and Macroeconomic Modelling

5.1.1 Dynamic Models of Monetary Economy

Dynamics of monetary economy was analysed using a system of three or four differential equations describing different sectors of an economy, i.e., a commodity market, a money market, a price dynamics area, and so on. The conditions for more complex dynamics as chaos and limit cycles were investigated in the quite simple dynamic system. It was shown deterministic chaos and limit cycles may appear at this one. Applications of these results were focused on the theory of valuation of industrial firms. The industrial yield was computed by help of cross section production functions. For a computing of these cross section production functions the Cobb-Douglas production function was chosen. Its parameters were estimated from cross section data. For computing of expected industrial yield traditional neo-classical conditions were used. Expected industrial yield can be used as a

discount factor in discounted cash flow method of valuation of firm. [133]

5.1.2 Economic Model of Cycles

An economic model of cycles focused on the capital investment phenomenon was analysed as Van der Pol's equation. This one constitutes a model for analyzing of the dynamic behavior of self-excited oscillations. The other approach considered a system of the first order nonlinear differential equations where the Van der Pol's equation is connected to a feedback function controlled by a capital/output ratio parameter. A value of the potential gross domestic product YP is considered as an unit of the economic system.

5.2 Cooperation Model and Fuzzy Set Approach

The alternative model of fuzzy coalitional games in which the expected pay-offs of coalitions and players was developed. The results were summarized in the monograph [164]. New research was oriented to the concept of vague preferences which are modelled by fuzzy ordering relations. It was shown that the definitoric properties of ordering, like completeness, reflexivity, symmetry (or semi-antisymmetry) and transitivity are significantly modified if the fuzzy ordering is considered instead of the deterministic one. This research is aimed to the investigation of the concept of von Neumann solution of fuzzy cooperative games.

Further research was completed in the preparation of formal tools for processing fuzzy quantitative data. The method for modelling verbal vagueness connected with such data was suggested in the previous years. In this year, the

results were also summarized and one of their practical applications (in fuzzy timetable model) was analyzed [173]

Characterization of several classes of aggregation operators, especially for MCDM, with incorporated weights (importance) of single criteria and some newly proposed construction methods for aggregation operators presented in some of our papers and monograph extends the basis for computational intelligence. We have also shown the existence of lower and upper bounds in the classes of strict, nilpotent and continuous Archimedean t-norms with possible application in fuzzy control. In the same domain are important t-conorm with moderate growth. We have shown that they are either generated by convex additive generators or the ordinal sums of the previous ones.[183], [182]

5.3 Stochastic Optimization

5.3.1 Stochastic Programming and Decision

Two special (rather complicated) types of the stochastic optimization problems were investigated from the stability and empirical estimates point of view. First, multistage stochastic (generally nonlinear) programming problems with general type of the constraints were considered. The Wasserstein and the Kolmogorov metrics were employed to obtain the new stability results. The both metrics were considered with respect to the Euclidean space of the dimension equal to the dimension of the random elements in the "decomposed" (with respect to the eventual time points) stochastic programming problems. The corresponding random sequences were assumed to be autoregressive or at least it was assumed that they fulfil the Markov condition. Furthermore, a behaviour of the (optimal value) empirical estimates was inves-

tigated. The achieved stability results as well as the achieved empirical estimates results for the multistage stochastic nonlinear programming problems (see [111], [112], [113]) generalize the well-known results achieved sooner for one-stage problems. Furthermore, the empirical estimates of the efficient points set (in the case of the multi-criteria stochastic programming problems with the individual probability constraints) were investigated. The exponential rate of the convergence (under rather general assumptions) was proven for this type of the problems (see [114]). This result generalizes the well-known results for the one-objective stochastic programming problems to the multi-objective case.

5.3.2 Comparison of Multistage Stochastic Programs with Recourse and Stochastic Dynamic Programs with Discrete Time

When solving a dynamic decision problem under uncertainty it is essential to choose or to build a suitable model taking into account the nature of the real-life problem, character of input data, availability of software and computer technology. Similarities and differences of two candidate approaches connected with discrete time decision processes and with uncertainties of probabilistic nature, i.e. multistage stochastic programs with recourse and stochastic dynamic programs with discrete time were investigated. Advantages and disadvantages of both approaches were illustrated on examples.

5.3.3 Variance Penalized Stochastic Optimization

Mean variance selection rules were originally proposed for the portfolio selection problems. Following the mean variance selection rule, the investor selects from among a given

set of investment alternatives only investments with a higher mean and lower variance than a member of the given set. Investigation how the mean variance selection rules can work in discrete dynamic stochastic models was performed. Alternative definitions of the reward variance along their mutual connections and their connections to various specific formulas for the variance of number of transitions between selected states of a classical Markov chains were discussed. Attention was focused on finding policies (i.e., sequences of decisions) minimizing the long run reward variance on condition that the mean reward is not less than a given value.

5.4 Theoretical Finance

5.4.1 Consumption-based Capital Asset Pricing Model

A model of asset pricing in a decentralized multi-dealership market. This is a generalization of the standard CCAPM (Consumption-based Capital Asset Pricing Model) pricing formula for the case when the investor-dealer order flow is accounted for explicitly.[42] The obtained theoretical asset pricing formula can be applied to explaining anomalies in the price behavior of certain financial market segments of transitional economies.[43]

5.4.2 Expectation Heterogeneity

The heterogeneity of expectations among traders introduces an important non-linearity into the financial markets. The financial markets are considered as adaptive belief systems. Asset price fluctuations in adaptive belief systems are characterized by phases of close-to-the-fundamental-price fluctuations, phases of optimism where most agents follow an

upward price trend, and phases of pessimism with small or large market crashes. The Efficient Market Hypothesis benchmark and forecasting rules of fundamentals and trend extrapolators have discussed [250]. An influence of the heterogeneity of expectations among traders to the economic stability has intensively analysed by mathematical structure model [249].

6 Department of Pattern Recognition

Head of Department:

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Secretary:

Eva Maléřová – Phone & Fax: (+420-2) 8468 3031
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Research Fellows:

Jiří Grim – Probabilistic neural networks, method of finite mixtures
e-mail: grim@utia.cas.cz

Michal Haindl – Spatial data modelling, model-based pattern recognition, virtual reality
e-mail: haindl@utia.cas.cz

Jana Novovičová – Statistical approach to pattern recognition: feature selection and classification methods and criteria
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Petr Somol – Statistical Pattern Recognition
e-mail: somol@utia.cas.cz

Postgraduate Students:

Pavel Žid – Image Segmentation

Vojtěch Havlíček – Texture Synthesis

Pavel Paclík – Statistical Pattern Recognition
Antonín Malík – Statistical Pattern Recognition

Grants and Projects

- P. Pudil, “Multidisciplinary approaches to support of decision-making in economics and management”
Continuation of the Grant No. VS96063 of the Ministry of Education in the form of oriented research (in cooperation with the Faculty of Management, University of Economics Prague);
- P. Pudil, “Interactive Presentation of Census Results by Means of Probabilistic Models”
Grant Agency of the Czech Republic; No. 402/01/0981
- M. Haindl, “Texture Modelling”
Grant Agency of the Czech Republic; No. 102/00/0030
- M. Haindl, “Computer Aided Quantitative Fractography of Fatigue Failures”
Grant Agency of the Czech Republic,
No. 106/00/1715;

PhD Projects:

- 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 Mathematics, Charles University
Bok M: “Consulting System for Feature Selection”
Supervisor: P. Pudil
- Faculty of Transportation Sciences, Czech Technical University, Prague
P. Paclík: ”Road Signs Recognition Problem”
Supervisor: J. Novovičová
- Faculty of Electrical Engineering, Czech Technical University, Prague
A. Malík: ”The Use of Mixture Models for Text Document Classification.”
Supervisor: J. Novovičová

MSc Diploma Projects:

- Faculty of Electrical Engineering, Czech Technical University, Prague
J. Filip: “Colour Movies Scratch Restoration”
Supervisor: M. Haindl

University Courses:

- Faculty of Management, University of Economics, Prague
P. Pudil: ”Fundamentals of Statistics”
P. Pudil: ”Applied artificial intelligence for management”
- Faculty of Transportation Sciences, Czech Technical University

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

International Co-operation:

- Representation in international bodies:
M. Haindl — Chairman of the IAPR Publication and Publicity Committee
M. Haindl — member of the ERCIM - Editorial Board
P. Pudil — member of the IAPR Governing Board (representative of the Czech Republic)
P. Pudil — External PhD examiner for Cambridge University

- Co-operation on statistical approach to pattern recognition:
P. Pudil, J. Novovičová, J. Grim, P. Somol — University Surrey, GB; University of Valencia, Spain, University of Hokkaido (joint research project), University of Salzburg (joint research project)

P. Pudil, J. Novovičová, P. Somol — University of Cambridge, GB
P. Paclík — Delft University of Technology, The Netherlands

- Co-operation on image data modeling:
M. Haindl — University Surrey, GB; University of Auckland, New Zealand

P. Paclík — Delft University of Technology, The Netherlands

Conferences

- Advances in Pattern Recognition, Rio de Janeiro, Brasil, April 2001
- 5th International Conference on Artificial Neural Networks and Genetic Algorithms, ICANNGA 2001, Prague, Czech Republic, April 2001
- ETK-NTTS 2001, Crete, Greece, June 2001
- Multiple Classifier Systems, Cambridge, UK, July 2001
- Mixtures 2001, Hamburg, Germany, July 2001
- Pattern Recognition in Information Systems, Setubal, Portugal, July 2001

Research Scope

- Statistical Pattern Recognition
- Model-Based Pattern Recognition
- Random Field Modelling
- Method of Finite Mixtures
- Probabilistic Neural Networks
- Virtual Reality

Research Results

The scope of the Department of Pattern Recognition activities covers pattern recognition, with emphasis on statistical feature selection, model-based pattern recognition, probabilistic neural networks, modeling 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 principles of prediction used in the Fast Branch and Bound algorithm have been utilized for optimization of partial ordering of the computational tree nodes. The result is a breakthrough in the methodology of optimal algorithms for feature selection in classification and recognition, extends the applicability of prediction mechanism also for non-recursive criteria. It was presented to the international community at the ICAPR'2001 (International Conference on Advances in Pattern Recognition) in Rio de Janeiro [219].

6.2 Method of Finite Mixtures

Distribution mixtures with product components can be viewed as the models of conditional independence which are advantageous in application e.g. to estimating discrete probabilistic models [50] and pattern recognition [53]. Unfortunately, in case of discrete variables the conditional independence models are not uniquely identifiable. The practical aspects of this problem are discussed in a paper presented

at the conference “Mixtures’2001” in Hamburg [49, 48]. We propose a simple method of a sequential identification of components for a unique estimation of the conditional independence models by means of EM algorithm. The application of the method is illustrated by a numerical example.

At the “ETK-NTTS 2001” conference on Crete, Greece we presented new results relating to the recently proposed method of interactive user-friendly presentation of census results by means of the probabilistic expert system PES. The method is based on estimating a probabilistic model of the original microdata in form of a discrete distribution mixture which can be used as a knowledge base of PES. The final software product derives the statistical census information interactively from the estimated model without any risk of disclosure of individual respondents (cf. [50]).

At the ICANNGA 2001 conference, the algorithm for choosing the optimal number of components and corresponding component initial parameters for finite mixture fitting has been presented. A method for the complete mixture initialization based on a product kernel estimate of probability density function is proposed. The mixture components are assumed here to correspond to local maxima of optimally smoothed kernel density estimate. The gradient method is used for finding the maxima and agglomerative hierarchical method merges the closest components together. Experimental comparison to the scale-space approaches for finding the number of components is given ([194]).

6.3 Probabilistic Neural Networks

The multiple classifier fusion proved to be a useful tool to improve the classification accuracy in pattern recognition. In

this connection a general scheme of parallel classifier combinations has been considered for the sake of information analysis of the underlying data processing [53]. Unlike usual combining schemes the output variables of classifiers defined in terms of posterior probabilities are combined in parallel in the framework of the probabilistic neural networks. The statistical Shannon information is used as a criterion to compare different combining schemes from the point of view of the theoretically available decision information. By means of relatively simple arguments we derive a theoretical hierarchy between different schemes of classifier fusion in terms of information inequalities.

6.4 Markov Random Fields

The theory of random field models is one of the basic tools for modelling spatial, temporal and spectral relations in model-based pattern recognition and image processing tasks. Several Markov random field and wide sense Markov random field models, and problems with their parameter estimation, synthesis and optimal contextual support set detection were our primary research interest. Research results were applied in natural monospectral and colour texture modelling [59], colour image restoration, restoration of colour movie scratches [58], crack velocity modelling from microfractographical images, and in automatic acquisition of virtual reality models [58], [61] applications.

We have proposed a novel probabilistic discrete mixture model for monospectral textures [51], [52], and a novel 3.5 dimensional causal adaptive autoregressive model together with their analytical parameter estimators.

An original colour image restoration algorithm using a combination of 3 dimensional causal and non-causal weak Markov models was developed. The method is fully adaptive, numerically robust but still with moderate computation complexity. Its restoration quality is comparable with the best current image restoration methods while being much faster. Multiresolution approximations of a causal weak Markov colour texture model together with its parameter estimation and synthesis were proposed. The model enables to describe complex spatial relations due to independent Markov submodels for single spectral and frequency factors.

7 Department of Image Processing

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Visitor:

Jaroslav Kautský – Flinders University, Adelaide,
Australia

Grants and Projects:

- J. Flusser - Image fusion methods for degraded and incomplete data (Grant Agency of the Czech Republic, No. 102/00/1711 – jointly with the Astronomical Institute, Academy of Sciences of the Czech Republic)
- J. Flusser - The influence of a rearing environment of the welfare of dairy cows evaluated using thermographic methods (Grant Agency of the Czech Republic, No. 523/99/1489 – jointly with the Research Institute of Animal Production)

- B. Zitová - Geometric registration of degraded images (Grant Agency of the Czech Republic, No. 102/01/PO65)

University Courses:

- | | |
|--------------------------------|--|
| Jan Flusser | – “Digital Image Processing” at the Faculty of Mathematics and Physics, Charles University, Prague. |
| Jan Flusser and Barbara Zitová | – “Image Processing and Pattern Recognition”, at the Faculty of Nuclear Science and Physical Engineering, CTU, Prague. |
| Dana Klimešová | – “Geographical Information Systems and Image Processing” 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. |
| Lubomír Soukup | – “Adjustment of Geodetic Networks” at the Faculty of Civil Engineering, CTU, Prague. |
| Barbara Zitová | – “Digital Image Processing”, University of Veracruz, Mexico. |

The research activity is focused on the following areas:

- Theory of the invariants
- Recognition of distorted images and patterns
- Image fusion
- Image restoration
- Applications in remote sensing, astronomy, medicine, agriculture, geodesy and geophysics

7.1 A New Wavelet-Based Measure of Image Focus

The problem of selecting the best-focused image from a sequence of differently defocused/blurred images of the same scene often arises in many application areas, such as computer vision, industrial visual inspection, digital microscopy, remote sensing, and astronomy, among others. The goal is to select "good" images for visual interpretation or further computer analysis. Having a reliable and robust focus measure (or, inversely, blur measure) is a key point to resolve these problems.

We assume the relationship between the original scene $f(x, y)$ and the acquired set of images $g_1(x, y), \dots, g_n(x, y)$ can be expressed by convolution

$$g_i(x, y) = (f * h_i)(x, y), \quad i = 1, \dots, n \quad (1)$$

where $h_i(x, y)$ is the point-spread function (PSF) of the blur in the i -th observation. In the best possible case (not occurring in practice), $h_i(x, y) = \delta(x, y)$ and we get ideal image $g_i(x, y) = f(x, y)$. In practice all the $h_i(x, y)$ have a character of an unknown low-pass filter.

By the term "focus measure" or "blur measure" we understand any functional defined on the space of image functions which reflects the amount of blurring introduced by $h_i(x, y)$. Thus, having focus/blur measure M , we look for the "best" image $g_{i_0}(x, y)$ by maximizing/minimizing $M(g_i)$ over $i = 1, \dots, n$. Furthermore, we may also want to order the images according to their quality, which is equivalent to ordering the sequence $\{M(g_i)\}$, $i = 1, \dots, n$.

Any reasonable focus measure should satisfy some basic requirements. First, it should be content-independent, which means it must not be based on any particular structures in the image (e.g. on isolated bright points). Secondly, it should be monotonic with respect to blur. The more blurred the image, the less the focus measure should be. Finally, the measure should be robust to noise.

In the recent literature, variance of image gray levels, image moments, norm of image gradient, norm of second derivatives, and energy of image Laplacian were proposed as focus measures. We introduce a new focus measure defined by means of wavelet transform of the image.

Discrete wavelet transform of image f using a wavelet w produces a low-pass band $l_w(f)$ and several high-pass bands which we denote collectively by $h_w(f)$. We propose a new wavelet-based measure as a ratio

$$W = \frac{\|h_w(f)\|}{\|l_w(f)\|}.$$

This measure was proved to be monotonic with respect to the amount of blurring and sufficiently robust to additive noise (the robustness increases with the depth of the wavelet decomposition). It was shown that, in most cases, it provides better discrimination power than the earlier focus measures.



Figure 1: Indoor scene: Focused image (top left), slight out-of-focus (top right), medium out-of-focus (bottom left), heavy out-of-focus (bottom right).

We present here one of the experiments we have done. A static indoor scene was captured four times by digital camera (see Fig. 1). The first image was taken using camera autofocus, the others were manually defocused in such a way that the degree of out-of-focus was changing gradually from slight to heavy.

For each image we calculated five focus measures: gray-level variance, energy of image Laplacian, and our measure W using three different Daubechies wavelets (see Table 1). One can see from the monotonicity of the rows of Table 1 that each measure ordered the images correctly. All three

Image	Focused	Slight defocus	Medium defocus	Heavy defocus
Gray level variance	1	0.92	0.88	0.82
Laplacian energy	1	0.22	0.17	0.14
$W(4 \text{ taps, depth } 1)$	1	0.34	0.30	0.28
$W(4 \text{ taps, depth } 2)$	1	0.48	0.39	0.32
$W(10 \text{ taps, depth } 2)$	1	0.41	0.32	0.29

Table 1: Various focus measures calculated for the indoor images. Proportional values are used, 1 stands for the best focused image in the sequence.

wavelets provide very good discrimination because the most defocused image has low proportional measures. The same is true for Laplacian. On the other hand, the most defocused image measured by gray-level variance yields 82%, which does not provide enough space to distinguish among the images reliably.

For more detailed description of this method see [117].

Financial support of this research was provided by the Grant Agency of the Czech Republic under the projects No. 102/00/1711 and No. 102/01/P065.

7.2 Combined Blur and Affine Invariants

Recognition of objects and patterns that are deformed in various ways has been a goal of much recent research. The degradations (geometric as well as radiometric) are introduced during the image acquisition process. Finding a set of invariant descriptors is a key step to recognizing degraded

objects regardless of the particular deformations. An important class of radiometric degradations we are faced with often in practice is image blurring. Blurring can be usually described by a convolution $g(x, y) = (f * h)(x, y)$, where f is an original (ideal) image, g is an acquired image and h is a point spread function (PSF) of the imaging system. However, in a real world, the imaging geometry is projective rather than rigid-body. If the scene is flat and the camera far from the object in comparison to its size, the projective transform can be well approximated by an affine transform. Thus, having combined affine-blur invariants is in great demand.

As we proved earlier, blur invariants can be defined as

$$C(p, q)^{(f)} = \mu_{pq}^{(f)} - \frac{1}{\mu_{00}^{(f)}} \sum_{n=0}^p \sum_{\substack{m=0 \\ 0 < n+m < p+q}}^q \binom{p}{n} \binom{q}{m} C(p-n, q-m)^{(f)} \cdot \mu_{nm}^{(f)}, \quad (2)$$

where μ_{pq} 's are central moments of the image f and $(p+q)$ is odd. The $C(p, q)$'s are invariant to convolution with any centrosymmetric function $h(x, y)$, i.e.

$$C(p, q)^{(f)} = C(p, q)^{(f * h)}.$$

Affine transform of spatial coordinates (x, y) into (u, v) is defined by equations

$$\begin{aligned} u &= a_0 + a_1x + a_2y, \\ v &= b_0 + b_1x + b_2y. \end{aligned} \quad (3)$$

Affine moment invariants can be derived by the fundamental theorem: If the binary form of order p has an algebraic invariant of weight w and order k

$$I(a'_{p,0}, \dots, a'_{0,p}) = \Delta^w I(a_{p,0}, \dots, a_{0,p})$$

(Δ denotes the determinant of the respective affine transform) then the moments of order p have the same invariant but with the additional factor $|J|^k$:

$$I(\mu'_{p0}, \dots, \mu'_{0p}) = \Delta^w |J|^k I(\mu_{p0}, \dots, \mu_{0p}),$$

where $|J|$ is the absolute value of the Jacobian of the affine transform.

Our major result achieved on this field is a proof of the theorem claiming that the Combined Blur and Affine Invariants can be constructed by substitution of the blur invariants $C(p, q)$ for the corresponding moments μ_{pq} in the affine moment invariants. If $I(\mu_{00}, \dots, \mu_{PQ})$ be an affine moment invariant, then $I(C(0, 0), \dots, C(P, Q))$, is a combined blur-affine invariant.

More details can be found in [226].

Financial support of this research was provided by the Grant Agency of the Czech Republic under the project No. 102/00/1711.

7.3 Application of image processing for the conservation of the medieval mosaic

Up-to-date methods of image processing were used for the analysis of the "The Last Judgement" mosaic conservation. The mosaic, completed in 1371, is situated on the St. Vitus cathedral in Prague, Czech Republic. It is made of almost 1 000 000 glass cubes. Its decay has been severe, due to various factors such as the low quality of the used glass, the temperature fluctuations and the air pollution. The last conservation attempt was realized by the U.S. Getty Conservation Institute jointly with Czech specialists (1992-2001).

Recently, an old photograph (1879) of the mosaic was discovered in the archive. It was confronted with the photograph of the current mosaic state. The aim was to find mutual differences and reveal original but already lost patterns captured on the old photograph. The image was firstly preprocessed to increase its quality. The old photograph was noisy and blurred due to the wrong setting of the camera focus and due to the aging effect (silver particles are subject to the irreversible chemical process of diffusion). Most of the image degradation processes can be modelled by linear shift invariant system $g = f * h + n$, where g , f , h , and n represent an degraded image, original image, point spread function (PSF) and additive noise, respectively. The operator $*$ stands for the convolution. Various methods for image restoration were applied. Considering the image denoising, the wavelet-based denoising with automatic noise level estimation gave the most favorable results. For the image sharpening, we have applied the inverse heat equation method, the Wiener filter and an iterative reconstruction algorithm based on total variation, used in blind (without the information about the PSF) and non-blind framework. The latter mentioned gave the most satisfactory results (the Gaussian function was used as the representation of the PSF).

In the second stage, before the detection of mutual differences, the geometrical correspondence of images had to be assured (since the images were taken from different locations of the camera their geometry was different). The big difference between our images due to the violation of intensity values correspondence, blurring, scratches, noise, etc. demands a feature-based registration approach which does not use directly the image functions but extracted features and their estimated correspondence. Salient point pairs (corners,

edge endings, etc.) were detected and their correspondence was used for the computation of parameters of the mutual geometric transform. We used the affine, the projective and the thin plate spline models. The affine transform model proved to be sufficient.

Finally, after overlaying the already geometrically registered images of the old and new mosaic state, mutual differences of the photographs, not visible before, became apparent. We were able to identify differences (examples of the differences are shown in Fig 2.), which were new to the art historians and which could bring new ideas to the understanding of the mosaic.

This work has been supported by Prague Castle Administration.

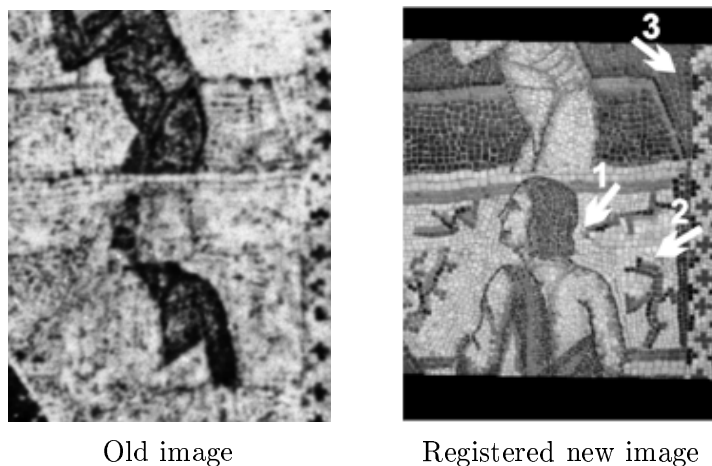


Figure 2: Examples of identified differences between the registered images. Coffin image sequence: (1) the haircut, (2) the ornamental patterns, (3) the coffin edge.

7.4 Detection of additional manipulations in digital images

The goal of the project is to develop methods for automatic or semi-automatic detection of changes of the image content that could be made intentionally in order to hide or falsify the reality. Such images may appear as evidence at a court, for instance. Since the manipulations can be of different kind, there cannot exist any universal detection method. In this project, we focused mainly to the detection of hidden discontinuities that often appear as a side effect when changing the image content.

By the term "discontinuity" we understand any sudden change of intensity values. However, such a definition covers also edges, corners and other high-frequency structures, which are organic parts of any image. Methods for manipulation detection should handle this ambiguity.

The methods for discontinuity detection can be categorized into three major groups:

1. Differential operators in space domain
2. Methods based on curvature of the intensity function
3. Wavelet-based methods.

In discontinuity detection, appropriate image pre-processing plays a very important role. Among many existing techniques we have tested, the best performance for this purpose is achieved by using heat equation for edge-preserving noise suppression and iterative blind deconvolution scheme for image de-blurring. For discontinuity detection itself, very promising results were achieved by application of Maar filters (second-order derivatives of the intensity

function combined with Gaussian smoothing) and, particularly in case of so-called cloned images, by Fourier analysis.

In the future research we propose to pay attention to the contextual analysis of the image. Inconsistency in 3D structure of the objects, in their mutual positions, in occlusions and shading may indicate additional manipulations such as removing, replacing and implanting of the objects. Another direction of research on this field is a detailed study and categorization of the physical properties of individual cameras. This would enable to recognize whether or not the image is a combination of several original images acquired by different cameras.

More details about this project can be found in [252].
This work has been supported by the Ministry of Interior under the project No. RN 19992001003.

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Grants and Projects

- J. Kadlec – *Centre of Applied Cybernetics* (LN00B096 The Ministry of education of the Czech Republic, 2000-2004)
- J. Kadlec (J. Schier) – *High Speed Logarithmic Unit* (ESPRIT 33544 Long Term Research, 1999-2001)
- J. Kadlec (A. Heřmánek) – *”RECONF 2” Design Method-*

ology and Environment for Dynamic RECONFigurable FPGA (No. IST-2001-34016, 2001-2004) negotiation phase of the project

- M. Kadlecová – *”IDEALIST-5FP” Information Dissemination and European Awareness Launch for the IST Programme under the 5-th Framework Programme* (No. IST-1999-14184, 2000-2003)
- J. Kadlec (D. Feiková, A. Rektorová) – *”CEeB” Promoting Cooperation of Central Europe in eBusiness* (No. IST-2000-31059, 2001)
- J. Schier – Research projects IMEC/Universities, period 1996-2001, project “Spatial Division Multiple Access Systems for Mobile Communications”
- M. Líčko, J. Kadlec – *Establishment of an intergrated design flow for embedded systems (IDF-EMSYS)* (program KONTAKT CZE 01/019)
- J. Kadlec – *Expert for the IST programme* (The Ministry of education of the Czech Republic, 1999-2004)

University Courses

The members of the DSP group give these selective post-graduate courses:

- Faculty of Electronic Engineering, Czech Technical University
Adaptive methods for signal processing (J. Kadlec)
Parallel algorithms and architectures (J. Kadlec)

Conferences, Workshops and Seminars

We have organized or co-organised several conferences related to EU projects in the area of IST (Information Society Technology):

- Two day international workshop ”Next Generation Net-

work". 19.-20.3.01, Hotel Krystal, Prague; 150 participants. Co-organised with Technology centre AS CR.

- One day international workshop "European IT Research Programme (IST), Successful Proposal Writing", Dresden, Germany, 17.9.01. 46 participants. Co-organized with IDEALIST NCP from Germany, Poland, Belgium and Holland.
- One day international workshop "European IT Research Programme (IST), Successful Proposal Writing", UTIA, 26.9.01. 54 participants Co-organized with IDEALIST NCP from Germany, Austria, Poland, Belgium and Holland
- Two day international workshop "Opportunities in the European Union's IST Programme" , 13.-14.11.01, UTIA; 63 participants. Key speakers: Dr. P. Drath and M. Schoefield, UK. Organised by project CEeB with Polish NCP organization.
- Two day international workshop "Opportunities in the European Union's IST Programme" and brokerage event, 23. - 24. 11. 01, Mragowo, Poland. Key speakers: Dr. Paul Drath, UK, A. Siemaszko, Poland; 50 participants. Organised by project CEeB with Polish NCP organization.
- One day international workshop "Managing EC Research projects" and brokerage event, 11.12.01, Hotel Diplomat Prague. 60 participants. Key speakers: Dr. Paul Drath and M. Schoefield, UK. Organised by project CEeB with Polish NCP organization.
- Preparation of the IDEALIST Stand at the Exhibition IST'01 Düsseldorf, Germany, 3.- 5.12.2001.

Guests

- *Dr. Felix Albu* University College Dublin, Ireland.
- *Dr. Chris Softley* University of Newcastle, UK, two visits.
- *Dr. Bohumir Sviežený*, ISEP - Institut Supérieur

D'Electronique de Paris, France.

- *Dr. Nicholas Coleman*, University of Newcastle, UK.
- *Students ISEP* 3-weeks stay of 7 students from ISEP, Paris, France.
- *Dr. Paul Drath* Singleimage, Ltd., UK.
- *Dr. K. Trojanowski, Dr. P. Martynowicz* FP5 National Contact Point, IPPT PAN, Poland.
- *Dr. Jiri Kaufhold* Cadence, Canada.

Travel and International Cooperation

Our travel was related mainly to participation in international conferences, coordination and working visits related to EU projects:

- B. Kovář, M. Tichý, ICANNGA 2001, Prague, contribution [228].
- M. Líčko, Embedded Intelligence 2001, N'urberg, DE, contribution [108].
- J. Kadlec, CELOXICA'01, Stratford, UK, contribution [107], [106].
- J. Kadlec, A. Heřmánek, Z. Pohl, 11th International Conference on Field Programable Logic and Applications (FPL 2001), Belfast, UK, contributions, posters [4].
- R. Matoušek, Philips Research Holland, co-operation on the EU project ESPRIT HSLA 33544
- J. Kadlec, University College Dublin, IRL, EU project ESPRIT HSLA 33544
- M. Líčko, University Miskolc, HU, study stay, conference MicroCad'01 participation.
- J. Kadlec, A. Rektorová, M. Kadlecová, MTA SZTAKI, HU, co-ordination meeting of the project IDEALIST.
- J. Kadlec, DATE'01, Munich, DE, participation.
- A. Heřmánek, ESAT Leuven, BE, visit.

- J. Kadlec, DERA Malvern, UK, visit.
- J. Kadlec, Adaptive Signal Processing Systems 01, ESAT Leuven, BE, participation.
- A. Heřmánek, INT-EVRY a MATRA - Velizy, FR, preparation of EU project RECONF 2.
- J. Kadlec, M. Líčko, R. Matoušek, ASDA'01 Brokerage event, FEI STU Bratislava, SK, presentation.
- J. Kadlec, Ljubljana, SI, preparation of EU project DRIOSH.
- J. Kadlec, A. Heřmánek, A. Rektorová, M. Kadlecová, Dresden, DE, organization of the IDEALIST international workshop.
- A. Heřmánek, MATRA - Velizy, FR, preparation of EU project HIGHLAND.
- Z. Pohl, Conference e2001, Campo san Salvador Venice, IT, preparation of IDEALIST stand.
- D. Feiková, A. Rektorová, Mragowo, PL, organization of the CEeB workshop.
- J. Kadlec, M. Líčko, FZI Karlsruhe, DE, working meeting of the project KONTAKT.
- M. Líčko, FZI Karlsruhe, long-term study visit, project KONTAKT.
- J. Kadlec, EC Brussels, BE, negotiation of the EU project RECONF 2.
- J. Kadlec, IST Committee as CZ representative Brussels, BE, (monthly).
- J. Kadlec, Exhibition IST'01, Düsseldorf, preparation of IDEALIST stand.
- A. Heřmánek, M. Líčko, R. Matoušek, Z. Pohl, MATLAB'01, Prague, contributions [78], [153], [154].
- B. Kovář, University of Delft, NL. Long-term study stay abroad.

- J. Schier, ESAT SISTA, KUL Leuven. Long-term stay abroad. Research in the area of subspace methods.

RESULTS

Key Directions of the Group

Theory of identification [103], algorithmic design [39] and mapping on parallel systolic arrays [102].

Applications in general area of digital signal processing [1], prediction, noise cancellation, and adaptive equalisation [4], [2].

Implementations based on rapid prototyping techniques [229] for embedded systems [210], signal processors [153] and field programmable gate arrays [4].

Applications and implementations [154] are the key factor for our work-motivation and help us to select the appropriate theoretical research themes, needed for successful solution of challenges of our research and development projects.

Our research is focused on new fast systolic estimators [2] with increased numerical stability with respect to insufficiently informative data. Bayesian probabilistic approach is used as a tool for analysis of normalised identification algorithms for fixed-point signal processors [3].

Combination of the recent results in the area of Lattice filters [1], [4] with our links to the Bayesian research leads to new fast systolic algorithms for DSP applications equipped with determination of system structure or on-line testing of hypotheses [103].

We invest considerable part of our efforts to the research of modern design techniques for automated programming of

parallel algorithms known as rapid prototyping [210]. We can use the computing power provided by embedded multi-processor architectures [78]. This allows us to keep open path to implementation of these research results and to participate on advanced EU-funded research projects [38], [40].

We develop tools for rapid prototyping leading to automated conversion of code from the simulation level to the code for embedded signal processors working in real-time [153]. This includes the development of low-level drivers for advanced PCI peripheral devices.

Majority of our implementations is oriented towards creation of advanced software tool-boxes and packages [176], connected to advanced embedded digital signal processing hardware or field programmable gate arrays [210]. Examples:

- A novel 19 bit version of Logarithmic Arithmetical Unit (ALU) [104] has been designed in the form compatible with the hardware design flow DK1 of the UK based company Celoxica. This led to the reduction of internal memory requirement from 95 blocks (32-bit ALU) to only 4 blocks. This have opened compatibility with the low-cost SPARTAN devices.
- The VHDL processor design is debugged on our HW and the final layout is beeng implemented at the Phillips Research Laboratories in Eindhoven, Holland.

Our research is driven and partially determined by the objectives and requirements, which has to be formulated case-by-case with our partners in EU research and development projects.

Integral part of our work is the active promotion and help to the research groups in the Czech Republic in the area of

entering of proposals for the EU funded European research in the area of "Information Society Technology" [110].

This helps not only to the companies. It helps to build links between research and potential users. It helps us to specify, what might be needed as the outcome of our work.

8.1 Logarithmic Arithmetic Unit in FPGA

Implementation of floating point algorithms in FPGA (Field Programmable Gate Arrays) [175] creates an open problem [38]. One of possible solutions is the representation of floating point numbers as an integer (fixed point) logarithm (32 bit and 19 bit). Basic arithmetical operations can be performed in this Logarithm Numbering System (LNS) which is suitable for FPGA and ASIC implementation [108].

A bit-exact simulator of the LNS 32-bit and 19-bit hardware has been developed. The simulator is formed by a library functions in C, compatible with the DK1 Simulator from Celoxica and Matlab 6. This approach leads to a solution, which is suitable to VLSI and FPGA implementation.

We have achieved hardware implementation of the complete TWIN logarithmic ALU, operating with the clock frequency 50 MHz on the XILINX VirtexE FPGA device. The latency of the ALU is 8 clock cycles for ADD and SUB and just 2 cycles for all other operations. The complete TWIN ALU takes just 14 percent of the internal logical resources of the XCV2000E circuit.

The finished intellectual property core is handling all ADD, SUB, MUL, DIV and SQRT operations, including the NaN (Not a number) exceptions and the saturation on overflow/underflow. The unit has been implemented on the RC1000 board for the XCV1000 and XCV2000e FPGA circuits. This research is performed under the EU ESPRIT

33544 HSLA Long-term research project, coordinated by the University of Newcastle, UK.

8.2 FPGA implementation of European Logarithmic Processor

We have implemented and verified FPGA version of complete 32 bit European Logarithmic Processor (ELM). The VHDL processor design is debugged on our HW and the final layout is going to be implemented at the Phillips Research Laboratories in Eindhoven, Holland.

The design has been tested on the RC1000 FPGA board located in the PC. The design under development can be characterised by these targeted parameters:

- Theoretical peak performance 1GFLOP equivalent at 250MHz.
- SIMD instruction set (2-way for real add/subtract, 4-way for other operations).
- Logarithmic representation for real numbers offers range and precision comparable to single-precision floating-point.
- Up to 4 real multiply/divide/square-root per cycle.
- Up to 2 real add/subtract with 3/4 cycle latency.
- 4-stage pipeline with static branch prediction.
- Internal Harvard architecture served by independent 64KB 2-way set-associative code and data caches.
- Register-memory operations for easy programming and high code density.
- High bandwidth 64-bit data-bus.
- Built-in 2-channel DMA controller.

The planned ELM ASIC device will be the world's first device designed up to the commercial requirements (180 nm CMOS technology) to use logarithmic arithmetic for real arithmetic operations. Its arithmetic offers approximately

twofold improvements over floating-point, in terms of both speed and accuracy, over a variety of numeric-intensive applications. The ELM is designed to offer convenient access to a logarithmic arithmetic unit for all 32-bit numerical work. This research is pushing forward the level of the presently mastered engineering design capabilities in the Czech Republic towards new quality. Again, this is possible though the EU funded ESPRIT Long term research program 33544 HSLA.

8.3 Support for Simulink and RTW in Real-Time

Cooperation with FZI Karlsruhe, Germany and UNIS Brno have been started in 2001 under the project CZE 01/019.

Cooperation is focused on integration possibilities of the Processor Expert (PE) into MATLAB PE serves like a Delphy tool for HW designers. Basic integration of PE, Simulink and StateFlow using RTW was realized. Concept of the PE toolbox was proposed. Exploitation in automotive industry based on production code generation was studied. Simple 'window lifter' model was designed and evaluated on the HW using TargetLink, RTW and PE.

We see direct benefits coming from this international cooperation in these areas:

- Analysis of SMART car's devices / interfaces.
- Modeling, code generation and HW integration with the SMART car.
- Understanding of creation new MATLAB's components (own model components).
- Own support for the production code generation from Matlab can be implemented / used (tools like RTW or TL needn't be used).
- Familiarization with (evaluation of) Embedded Coder.

- Evaluation and comparison of production code generators (Embedded Coder, TargetLink, etc.).
- An interesting work can be offered / presented to students. BB Understanding of creation of new PE's beans (own HW and RT-OS related components).
- Integration of Embedded Coder / TargetLink and Processor Expert (basic steps for this were done).

8.4 Support for Czech an NAS Participation in EU Research Programmes

We co-ordinated "Support of new associated states (NAS)" section of IDEALIST project:

Problems faced by potential and actual participants from the NAS and NAS national support infrastructure had been analysed (by special questionnaire, survey, interview) and action plans for year 2001-02 were developed. Final report [110] have been compiled.

The strategy supporting NAS organizations and their participation in the action line VIII.1.6 "Extension of existing IST contracts with NAS partners" was developed together with DE partner. Based on a list of IST projects (delivered by EC and Cordis) IST co-ordinators were informed about VIII.1.6 opportunities.

The publication "Czech Republic - Information Society Technologies - Contacts 2001" was extended and published as a multimedia CD ROM in the co-operation with the Technology centre AS CR.

The partner-search data from the CD was published in an electronic searchable form (search via keywords and via key actions) on the Czech Idealist-east server at:

<http://www.utia.cas.cz/idealist-east/ISTcontacts/>

This directory has been advertised at the central EU web pages, IST National Contact Point pages. The CD ROM has been distributed (500 volumes) at the IST2001 conference in Düsseldorf, Germany.

This action has been positively acknowledged by the IST committee and it has contributed to the success of the Czech small and medium enterprises in future professional co-operation with the European partners.

Other project-partner and public-relation activities:

- Ideal-ist CZ database has been extended. Now it includes about 600 partners (mainly Czech small and medium companies and universities in the area of IT) with active interest in the EU IST programme.
- We have organised many personal and phone consultations with some of these interested partners in 2001.
- Two partner-brokerage events were co-organised with DE, PL, BE, and NL Idealist partners as a part of two international workshops in Dresden and in Prague. Three international workshops in Prague and Poland were organised under the project CEeB.
- J. Kadlec presented problems of participation in IST FP5 on Invex'01 in Brno.
- New CZ IDEALIST web page was created:

<http://www.ideal-ist.cz/>

8.5 Notebook for the Blind

Mechanical construction and software of notebook for blind people has been improved by R. Matulík in 2001.

This portable pocket-size notebook is equipped with synthetic speech and the special Braille keyboard.

Improvements have been made in the mechanical construction of the keyboard. Progress has been made in the preparation of the generic speech synthesis method for new generation of applications and tools for handicapped.

On the HW front, a new printed circuit board for the Xilinx programable circuit has been designed, manufactured and tested. The board will serve as the prototype equipment for the design of dedicated peripheral devices for blind users.

The new PCB board has been already used as a prototyping tool by the PhD students of the Centre for Applied Cybernetics.

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