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Contents

2^{nd} International Workshop on
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Session 1.

December 10, 2006, Morning
Chairman: Milan Mareš

Some Open Problems of Fair Division

[1]Milan Vlach

The problems of fair division have received much attention in recent years. Economists often focus their attention on fairness in the context of a finite number of perfectly divisible homogeneous commodities. In contrast, mathematicians tend to prefer working with a single divisible heterogeneous object and discussing the problem in terms of the cake-cutting metaphor.

We are concerned with situations in which the members of a group of individuals wish to divide a given divisible object in such a way that every member is satisfied with the piece he or she receives. The object in question may be heterogeneous and different members may value the same piece differently. The problem is very old but apparently the first modern framework for a rigorous analysis of this ever recurring problem was introduced by Steinhaus and his colleagues Banach and Knaster in the 1940's. Numerous results, some purely existential and non-constructive, some algorithmic, have been obtained over the past 60 years. We confine our discussion mainly to two outstanding open questions that resist a satisfactory solution.

One question is concerned with finding a procedure for constructing an envy-free division in situations when participants do not know the preferences of other participants. Envy-free division is one in which each member receives a piece that is at least as valuable to him or her as that which any other member receives. It has been shown that envy-free divisions exist under rather general assumptions. However these results have been established by means of highly non-constructive mathematical tools like fixed point theorems or Lyapunov's theorem on the ranges of vector measures. Then the problem is how to construct such a division by some satisfactory procedure in a finite number of steps. Quite satisfactory procedures are known for groups consisting of two or three members. More than a decade ago, a finite procedure for constructing envy-free division for four or more members was established. However, this procedure has an unpleasant feature: Even in the case of only four members, it has no upper bound on the number of necessary steps that is independent of the individual preferences.

More than ten years ago, using the cake-cutting metaphor, David Gale asked another question: "Suppose a pie is to be divided among three people and the pieces are required to be traditional pie portions, namely, sectors. Does there necessarily always exist an allocation which is envy-free and undominated?" Here domination is defined as follows: An allocation is dominated if there is another allocation which gives all members pieces they strictly prefer. While it is well-known that each envy-free allocation is always undominated in the case that pie is a nontrivial bounded closed interval and all pieces are required to be subintervals, Gale's question still awaits a solution.

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On divergences of finite measures and some statistical applications

[1]Wolfgang Stummer, [2]Igor Vajda

For convex functions ϕ (with some additional properties), we discuss ϕ-divergences of finite measures μ, ν defined in the following two different ways

1. $\overline{D}_\phi(\mu,\nu) = \int\, q\,\phi\left(\frac{p}{q}\right)\mathrm{d}\lambda$,

2. $D_\phi(\mu,\nu) = \int_{\mathcal{X}} q\,\tilde{\phi}\left(\frac{p}{q}\right)\mathrm{d}\lambda$,

where $\tilde{\phi}(t) = \phi(t) - \phi'_+(1)\,(t-1)$ with right-hand derivative $\phi'_+(1)$ of $\phi(t)$ at $t=1$, and λ is a σ-finite measure dominating $\{\mu,\nu\}$ with Radon–Nikodym densities $p = \frac{\mathrm{d}\mu}{\mathrm{d}\lambda}$ and $q = \frac{\mathrm{d}\nu}{\mathrm{d}\lambda}$.

After some investigations on the possible signs of $\overline{D}_\phi(\mu,\nu)$, we derive some lower and upper bounds for the divergences $D_\phi(\mu,\nu)$. Furthermore, we present some situations where the evaluation of ϕ-divergences of finite non-probability measures represents an important step of statistical inference. Special emphasis will be put on applications to the statistics of random right-censoring.

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On Bahadur efficiency in testing the goodness of fit

[1]Igor Vajda

Many problems of statistical decisions can be reduced to the situation than n balls are distributed into boxes $1, ..., k$. Observing the counts $\boldsymbol{X}_n = (X_{n1}, ..., X_{nk})$ of the balls in these boxes we have to decide whether the distribution of the balls is governed by a given stochastic law $Q = (q_1, ..., q_k)$. This problem is usually solved by means of one of the power divergence goodness of fit statistics

$$T_{n,a} = 2nD_{\phi_a}(\hat{P}_n, Q) = \sum_{j=1}^{k} q_j \phi_a \left(\frac{\hat{p}_{nj}}{q_j} \right), \quad a \in \mathbb{R}$$

for $\hat{P}_n = (\hat{p}_{n1} \equiv X_{n1}/n, ..., \hat{p}_{nk} \equiv X_{nk}/n)$ and for the functions

$$\phi_a(t) = \frac{t^a - a(t-1) - 1}{a(a-1)}, \quad a(a-1) \neq 0$$

of variable $t > 0$ with the corresponding limits $\phi_1(t), \phi_0(t)$. In many situations the problem can be transformed so that Q is uniform, $Q = (1/k, ..., 1/k)$. We shall assume that Q is uniform and $k = k_n$ possibly depends on n and increases slowly to infinity as $n \to \infty$. The relative quality of two tests $\mathcal{T}_{a_1}$ and $\mathcal{T}_{a_2}$ using the statistics T_{n,a_1} an T_{n,a_2} will be measured by the *Bahadur Relative asymptotic Efficiency* $\mathrm{BARE}(a_1, a_2)$. If $\mathcal{T}_{a_1}$ and $\mathcal{T}_{a_2}$ are equally asymptotically efficient then $\mathrm{BARE}(a_1, a_2) = 1$. The problem of existence of an optimal power divergence test $\mathcal{T}_{a_{opt}}$ for which

$$\mathrm{BARE}(a_{opt}, a) > 1 \quad \text{for all } a \in \mathbb{R}$$

is so far unsolved. Using results of the below cited papers we contribute to a partial solution of this problem.

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Advanced Blind Source Separation Methods and Their Application in EEG Data Analysis

[1]Petr Tichavský, [2]Jan Nielsen

Blind inversion of a linear and instantaneous mixture of source signals is a problem often found in many signal processing applications. Efficient FastICA (EFICA) [2] offers an asymptotically optimal solution to this problem when all the sources can be well-modeled as independent and identically distributed (i.i.d.) non-Gaussian processes.

Similarly, the Weights Adjusted Second Order Blind Identification (WASOBI) [5, 6] is asymptotically optimal when all the sources can be modeled as Gaussian Autoregressive (AR) processes. Nevertheless, real-life mixtures are likely to contain both Gaussian AR and non-Gaussian i.i.d. sources rendering WASOBI and EFICA severely sub-optimal.

We propose a novel scheme [7] for combining the strengths of EFICA and WASOBI in order to deal with such hybrid mixtures.

In the second part of the seminar, examples of application of EFICA, WASOBI and COMBI to blind separation of Electroencephalogram (EEG) data will be presented and discussed, cf. [3].

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Divergence-based tests of goodness-of-fit

[1]Tomáš Hobza

Pearson's χ^2 test, and more generally, divergence-based tests of goodness-of-fit are asymptotically χ^2-distributed with $m-1$ degrees of freedom if the numbers of cells m is fixed, the observations are i.i.d and the cell probabilities and model parameters are completely specified. Jiang (2001) proposed a nonstandard χ^2 test to check distributional assumptions for the case of observations not identically distributed. Under the same set up, in this contribution a family of divergence-based tests are introduced and their asymptotic distributions are derived. In addition bootstrap tests based on the given divergence test statistics are considered. Applications to generalized linear models diagnostic are proposed. A simulation study is carried out to investigate performance of several power divergence tests. Finally, some recommendations on the choice of test statistic based on the results obtained from Monte Carlo experiments are given.

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2^{nd} International Workshop on
Data - Algorithms - Decision Making

Session 2.

December 10, 2006, Afternoon
Chairman: Martin Janžura

Recent Advances in Model-Based Clustering: Image Segmentation and Variable Selection

[1]Adrian E. Raftery

Cluster analysis is the automated search for groups of related observations in a dataset. Model-based clustering bases cluster analysis on a finite mixture probabilistic model, allowing inference to be put on a formal statistical basis. This leads to maximum likelihood and Bayesian estimation of the model parameters, assessment of uncertainty about group classifications, formal inference about the number of groups present and the best clustering models, as well as robust methods for dealing with outliers. I will review model-based clustering and describe some applications to automated image processing, in particular the segmentation of functional MRI images of the breast for helping to detect tumors.

I will describe a method for deciding which variables should be used for clustering. This recasts the variable selection problem as a model selection one, leading to a solution based on approximate Bayes factors. In experiments, we found that removing irrelevant variables often improved performance, and led to more parsimonious clustering models and easier visualization of results.

Model-based clustering is implemented in the `mclust` package for the free `R` statistical language, available at `http://www.cran.r-project.org/`. Variable selection for model-based clustering is implemented in the `clustvarsel` package, available at the same website. Articles are available at `http://www.stat.washington.edu/raftery/Research/mbc.html`.

This is joint work with Nema Dean, Chris Fraley, Florence Forbes and Nathalie Peyrard.

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Probabilistic Projections of HIV prevalence Using Bayesian melding

[1] Leontine Alkema, [2] Adrian E. Raftery , [3] Samuel J. Clark

The Joint United Nations Programme on HIV/AIDS (UNAIDS) has developed the Estimation and Projection Package (EPP) for making national estimates and short term projections of HIV prevalence, based on observed prevalence trends in antenatal clinics. Understanding uncertainty in its projections and related quantities is important for more informed policy decision making.

We propose using Bayesian melding to assess the uncertainty around the EPP predictions. It uses prevalence data as well as information on the input parameters of the EPP model to derive probabilistic HIV prevalence projections; a probability distribution of a set of future prevalence. We relate antenatal clinic prevalence to population prevalence and account for variability between clinics using a random effects model. Predictive intervals for clinic prevalence are derived for model checking. We discuss predictions given by the EPP model and the results of the Bayesian melding procedure for Uganda. In Uganda, prevalence peaked at around 28% in 1990, the 95% prediction interval for 2010 ranges from 2 to 7%.

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Bayesian Melding in Urban Simulations

[1]Hana Ševčíková, [2]Adrian Raftery, [3]Paul Waddell

At the Center for Urban Simulation and Policy Analysis, University of Washington, we have developed a sophisticated open source simulation software, called UrbanSim [3], that simulates evolution in land use over a (possibly long) period of time. It is implemented as a system of models simulating behavior of different types of agents, such as households and jobs. The system is a part of the Opus project (Open Platform for Urban Simulation) which has been developed as a collaborative platform for researchers, modelers, developers and users involved in land use, transportation and environmental planning in urbanizing regions throughout the world.

Although the nature of the simulation system, including model structure, input parameters and data, is subject to uncertainty, UrbanSim - as many other simulation systems - essentially provides point predictions. Thus, it does not provide policy makers with information about the confidence of the predictions. As a result, uncertainty may be underestimated, and decisions may be made that are riskier than the policy-maker thinks they are.

In this talk, I will describe UrbanSim including its model components. I will introduce a method for assessing uncertainty about quantities of interest using urban simulation models, called Bayesian melding [2], [1]. In a case study we will compare results from our method with a method of a simple repetition of simulation runs. It will be shown that the simple repeated runs method gives distributions of quantities of interest that are too narrow, while Bayesian melding gives well calibrated uncertainty statements.

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A survey of research activities at FAV in filtering, detection and control

[1]Miroslav Šimandl, Jindřich Duník, Miroslav Flídr, Ivo Punčochář, Ondřej Straka

During the last two years, research work at the research centre Data- Algorithms-Decision Making at the Faculty of Applied Sciences (FAV), University of West Bohemia in Pilsen was focused on the following topics: Nonlinear Filtering Methods, Optimal Fault Detection and Control, Adaptive Control and Application of Filtering Techniques in Traffic Control. The important results, achieved in 2006, are introduced in the next part.

Nonlinear filtering methods. In particular, state estimation of nonlinear non-Gaussian stochastic systems was treated. An advanced point-mass (PM) method was designed. It consists of new algorithms which were built in a unified framework of point mass approach. The improvements of the basic PM method were achieved especially in the following issues: setting grid points to accomplish better estimation quality, reduction of computational demands and multigrid representation of multimodal pdf [1]. In particle filters area, the stress was laid on two key parameters affecting estimation quality, i.e. sampling densities and sample size setting [2]. New results were obtained in the local filter area as well. Algorithms for prediction and smoothing based on the Stirling interpolation and the unscented transformation were derived [4]. The results concerning distance based pruning in Gaussian sum approximation [6] and current state of the nonlinear filtering toolbox [7] are presented in other conference contributions.

Optimal Fault Detection and Control. Mostly, the fault detection problem is solved by open loop feedback information processing strategy (OLFIPS), which represents the passive detector design. The main goal was to use the closed loop information processing strategy (CLIPS) for the active detector design and therefore to use the future information for decision making. At first, a new compact formulation of the active fault detection and dual control was proposed. The formulation is based on the complete stochastic description of the system and the active detector design was stated as an optimization problem. Then three main cases, the active detector with the a priori given input signal generator, the active detector generating probing signal, and the active detector combined with the dual controller were solved using the CLIPS. It was shown that the CLIPS allows us to obtain better results in all three cases than the standard detector design approaches which are based on the OLFIPS [4].

Application of Filtering Techniques in Traffic Control. Extensive work was focused on an application of local filters, in particular the Extended Kalman filter and the derivative free filters, to state and parameters estimation of traffic models. The results were put together with the results concerning model design which were achieved in UTIA [5].

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Toolbox for nonlinear estimation

[1]Miroslav Flídr, Miroslav Šimandl, Jindřich Duník, Ondřej Straka

The aim of the contribution is to introduce a software framework written as a toolbox in MATLAB for state estimation of discrete time dynamic stochastic systems. The framework is designed to offer an easy to use tool for facilitating implementation, testing and use of various nonlinear estimation techniques. One of its main strengths lies in its high modularity and extensibility. The framework comprises implementation of various local and global state estimation techniques accompained with means for description and simulation of discrete stochastic systems.

The introduction briefly mentions evolution of the toolbox. The framework started from a set of scripts that just implemented the well known estimation methods [2] and that sufficed for simple testing of the methods to complete software framework [3]. The evolution from the first simple and limited toolbox was driven by the need of an elaborated framework with respect to ease of use and future extensibility. The current version of the toolbox [1] was thus built using principles of object oriented design i.e. inheritance, polymorphism and encapsulation. Those principles enable high modularity and reusability of the code making it possible to ease developing new or enhancing currently implemented estimation methods.

Improvements incorporated into the current toolbox version will be demonstrated. This version particularly brought enhanced capabilities in the way the user specifies the systems (and thanks to the used object methodology without need to change the estimation methods). The previous version required the Symbolic Toolbox for MATLAB for representation of the nonlinear multivariate functions. On one hand, this dependency was suitable for fast prototyping of the estimation experiments. However, on the other hand it limited the possibilities of the toolbox and also resulted in slower computation times. After partial refactoring of the model description part of the framework it is now possible to use a user-defined multivariate function. This brings more flexibility and can considerably fasten the computation. It should be noted that thanks to the object oriented design no changes were necessary in estimator implementation.

The last part of the presentation will be devoted to an outline of the future of the framework. The future version will provide means for a more general description of the system. The main feature will be availability of fully probabilistic design of the estimation experiment.

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Lissack-Fu Distance Based Pruning for Gaussian Mixtures

[1]Ondřej Straka, Miroslav Šimandl

The Gaussian sum (GS) method plays an important role in state estimation of the non-Gaussian systems [1]. In the case of a linear system with the state and the measurement noises given by a GS, the number of the terms in the filtering pdf increases exponentially and thus some reduction and approximation techniques must be proposed. Timing of the reduction (time update, measurement update, and sliding windows) may influence approximation quality significantly. It is possible to distinguish the three approaches to the reduction.

The pruning approach is based on cutting off some terms of the GS. The disadvantage of the approach is a local character of the reduction because the information of the cut-off terms is inevitably lost.

The merging approach is based on joining two or more terms into one preserving total mean and covariance matrix of the filtering pdf. The approach has a global character of the approximation because information of all terms survives in some sense.

The optimization approach is a set of intricate and sophisticated techniques based on for example the parameter optimization or the structural adaptation.

Both the pruning and the merging approaches are natural with a simple implementation, nevertheless they do not usually provide a quality approximation. On the other hand, the optimization approach offers quality approximation of the filtering pdf at the expense of high computational demands and theoretical complexity.

The proposed distance-based pruning technique should provide high quality approximation with low computational demands. It is designed for reduction of the terms of the filtering pdf which is given by a weighted sum of Gaussian distributions $p_1(x_k|z^k) = \sum_{i=1}^{\xi^1} \alpha_{ki}^1 \mathcal{N}\{x_k; \hat{x}_{ki}^1, P_{ki}^1\}$. The technique measures significance of each term of the sum using the Lissack-Fu distance [2] between the candidate approximate filtering pdf $p_2(x_k|z^k) = \sum_{j=1}^{\xi^2} \alpha_{kj}^2 \mathcal{N}\{x_k; \hat{x}_{kj}^2, P_{kj}^2\}$ and the filtering pdf $p_1(x_k|z^k)$

$$L_2(p_1, p_2) \stackrel{\triangle}{=} \int |p_1(x_k|z^k) - p_2(x_k|z^k)|^2 dx_k = \Xi_{11} - 2\Xi_{12} + \Xi_{22},$$

$$\Xi_{mn} = \sum_{i=1}^{\xi^m} \sum_{j=1}^{\xi^n} \alpha_{ki}^m \alpha_{kj}^n \mathcal{N}\{\hat{x}_{ki}^m; \hat{x}_{kj}^n, P_{ki}^m + P_{kj}^n\},$$

and prunes the insignificant terms. The idea is:

- to start with the approximate filtering pdf containing one term of the GS of the filtering pdf because at least one term has to remain after reduction
- to append other terms of the filtering pdf to the approximate filtering pdf successively
- to monitor how the approximate filtering pdf approaches the filtering pdf
- to assess whether the appended terms improve the approximation quality significantly
- if appending a term produces almost no approximation improvement, the term is discarded

The main idea of the thrifty implementation consists in computation of all terms in the sums Ξ_{11}, Ξ_{12} and Ξ_{22} in advance. Evaluation of the distance $L_2(p_1, p_2)$ consists in summation of corresponding pre-computed terms and normalization,

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Experiments with Distributed Bayesian Decision-Making

[1]Václav Šmídl, [2]Josef Andrýsek

Decision-making under uncertainty is a natural part of everyday life of every human being. In technical science, the process was formalized using probability theory yielding so called Bayesian theory of decision making [1]. However, one of the key assumptions of this theory is that the decision-maker is the only entity that intentionally influences the system. This assumption is certainly violated in more complicated systems, such as human society or distributed control. Recently, a series of papers attempts to offer an extension of the Bayesian theory for many decision-makers [2], i.e. multiple-participant decision-making.

Using this approach, a decentralized control of a large system can be achieved if the system is decomposed into parts, each of which is controlled by an autonomous controller (decision-maker). Then, the standard Bayesian theory can be used to design decision-strategy for each of the decision-makers. The main advantage of this approach is that the approach is naturally scalable. If the controlled system is shrinked or enlarged, it is sufficient to add or remove one or more decision makers. The main disadvantage is that autonomous decision-makers must have individual aims and models, which may result in design of conflicting control strategies. In order to avoid this problem two extra probabilistic operations were proposed:

1. merging of aims,
2. merging of models.

These operation synchronize the knowledge and intentions between participants and thus suppress or completely resolve possible conflicts. The main distinction between the two operation above is the use of a different calculus.

However, no proof of optimality of the proposed approach is available. Therefore, we study properties of the proposed algorithms in simulation. The first results of such simulations are presented in this paper. In the first experiment, we study a mathematical model of temperature control of an imaginary room. The actuators are individual cooling and heating units that are able to communicate to each other. The aim is to control the temperature without any central unit, i.e. each participant (cooler or heater) should estimate its model parameters and design its own strategy.

The model of the true temperature is a simple ARX model with external inputs from all participants. However, the participants model only part on the overall system, in this case, they are not aware of each other, i.e. they estimate an ARX model with a single external input for which they design control strategy. Under such conditions, the resulting control strategy must be sub-optimal. In simulations, we show that the proposed operations of merging of ideals and merging of models are capable of avoiding conflicts and improving performance of the resulting control scheme.

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Toolbox for Multivariate Adaptive Controller Design

[1]Miroslav Novák

Controller tuning is a basic step in any control application. This tuning is a complex process composed of several steps starting with the plant analysis and ending with the verification of the designed controller. There exist various tools that help in particular steps of the design but the complete path of the design is not supported. This work makes an attempt to offer a procedure of "complete" controller design where all necessary steps follow automatically one after another. The idea is applied here to the adaptive LQG controller design.

A Matlab toolbox Jobcontrol is being developed in order to merge the particular steps of controller tuning. The rough procedure is following: data preprocessing, structure estimation, parameter estimation, forgetting factor estimation, validation of identified model, *controller design and translation of aims*, and controller verification.

The first five steps utilize the Bayesian identification methods [1]. The controller design and translation of aims are the topics I am currently interested in [3] and I will focus on them in the presentation.

The controller is being designed according to the aims given by the user and the identified model. The user's aims considered are to minimize the output error and to keep given constraints placed on input quantities. The identified model is the ARX one. As the Bayesian approach is used, the parameters of the model are uncertain and are obtained in form of pdf.

The problem of controller design is that there is no practically usable controller available which is able to include directly such aims and model. Possible solutions of this problem are to approximate the model by a deterministic one as the GPC controllers do, to approximate the Bellman function in the dynamic programming, or to use an available controller which cannot fully include the requirements, but which can be easily calculated. The controller is tuned to satisfy at some level the requirements — this approach, controller tuning, is used in the presented Jobcontrol toolbox.

The controller tuning is nowadays mostly connected with the PID control, but in this work the LQG controller is used and tuned. The advantage is that it is model based and only its quadratic criterion is subject to tuning. Considering the uncertain parameters of the estimated ARX model this approach allows to tune the adaptive controller.

The tuning is done by a numerical sample-path optimization method utilizing functions evaluating the closed loop quality. As this evaluation is done by simulation, for every iteration of optimization method at least one simulation run is be performed. Thus a natural need is to keep the computational demands low. This is solved by utilizing the on-line stopping rules [2] that stops the simulation as soon as the estimates of the closed loop quality functions are stabilized. The level of stabilization is measured by the Kullback-Leibler divergence of their respective distributions.

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Bayesian Decision Support for Industry: Application Themes

[1]Pavel Ettler

Three themes for industrial utilization of decision-support algorithms are mentioned. Two of them concern recommendations for human decisions while the third one consists in internal system decisions on model selection. All of the topics come from the area of metal processing but their utilization potential is much wider.

- **Decision support for operators of the rolling mill**

  The work is continuation of research started by the international project [1]. The project was completed by integration of the decision-support tool into the control system for the 20-high cold rolling mill. The system is capable to generate recommendations for settings of several key process variables [2].

  Current research consists in on-line testing of new versions of algorithms. The first phase took place in winter and spring 2006. Main criterion of proper operation is based on comparison of settings made by an experienced operator with recommendations generated by the system. Due to variety of types of the rolled material and complexity of the machine on one side and number of system options on the other side the set of results is rather extensive and was summarized in the internal report [3].

- **Model mixing – predictions from short records**

  Plenty of short data records are available from a specific process concerning hot rolling. For a single record, number of samples is too small for reliable parameter estimation or even identification of the model structure.

  Special merging of records enables mixture identification. Components of the identified mixture represent particular models. Evaluation of component weights is the crucial task to allow usable output prediction. Three methods were elaborated and verified off-line on real data.

  Results were presented on the international conference [4]. Application in other areas such as medicine should be straightforward.

- **Evaluation and optimization of working shifts**

  Four groups of operators alternate in three-shift operation. Statistical comparison of their results is trivial but unfair because of unequal conditions. The research consists in conditioned probabilistic evaluation and consequent optimizing recommendations. Three levels of decision-support are considered: (1) the most demanding orders are entrusted to the shift with the best results for given material and conditions, (2) the best shift is selected to learn the others its settings and finally, (3) the system generates particular recommendations for machine settings to all of the shifts.

  System is in the stage of off-line tests. The report is being prepared.

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2^{nd} International Workshop on
Data - Algorithms - Decision Making

Session 3.

December 11, 2006, Morning
Chairman: Igor Vajda

A Statistical Approach to Local Evaluation of a Single Texture Image

[1]Jiří Grim, [2]Petr Somol , [3]Michal Haindl , [4]Pavel Pudil

The concept of texture implicitly suggests some local shift invariant statistical properties. Motivated by this idea we have shown in a series of papers that grey-scale textures can be modelled by estimating the joint probability density of grey levels in a suitably chosen observation window. The texture parts chosen by shifting the window can be viewed (in a vector arrangement) as observations of a random vector identically distributed with an unknown joint probability density. The method is based on estimation of the unknown probability density in the form of a normal mixture of product components by means of EM algorithm [1]. The mixture components defined as products of univariate normal densities are suitable to compute the related marginal and conditional distributions and therefore we can use a simple conditional expectation formula to synthesize arbitrarily large textures sequentially. The method proved to be practically applicable to different types of grey-scale textures [2] and in a slightly modified form it has been applied to model color textures [4] and even rough (BTF) color textures [5]. Comparing the synthesized textures with the original texture image we have an interesting possibility to verify the quality of the estimated density visually. In case of a successful texture synthesis we may assume that the underlying mixture density locally describes all essential statistical properties of the texture.

Motivated by the good experimental results [4, 5] we propose to apply the estimated density to a local evaluation of the source texture image. If we compute the mixture density at different positions of the window we obtain a quantitative measure of typicality of the corresponding texture pieces. At each window position we can assign to the central pixel a grey level which corresponds to the log-likelihood of its window neighborhood. The interpretation of the resulting log-likelihood image is straight-forward. The high grey levels correspond to the "typical" highly probable parts of the texture and the low values reflect the less-probable, "untypical" or "unusual" locations. The method can be applied e.g. to identify defects or abnormalities in grey-scale texture images.

The local statistical model can also be used to evaluate screening mammograms. In view of the fact that most mammograms are pathology-free the malignant abnormalities may be identified via novelty (outlier) detection. In this sense the log-likelihood image differentiates between typical and unusual parts of the original mammogram. In consequence of a specific artefact the locations of similar properties are partly distinguished by contour lines. In this way many diagnostically important details become visible and easy to identify. The resulting log-likelihood image is invariant with respect to arbitrary linear transform of the underlying grey scale.

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Feature Subset Selection for Text Categorization

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Text categorization is the task of automatically sorting a set of documents into predefined classes based on its contents. Text categorization may appear in many applications including e-mail filtering, mail routing, spam filtering, news monitoring, selective dissemination of information to information consumers, automated indexing of scientific articles, and so on. An increasing number of statistical classification methods and machine learning algorithms have been explored to build automatically a classifier by learning from previously labelled documents. The overview of Sebastiani [3] discusses the main approaches to text categorization.

In text categorization, usually a document representation using a *bag of words* approach is employed (each position in the feature vector representation corresponds to a given word). This representation scheme leads to very high-dimensional feature space, too high for conventional classification methods. Dimensionality reduction is a very important step in text categorization because irrelevant and redundant features often degrade the performance of classifiers both in speed and classification accuracy. In text categorization problem the dominant approach to dimensionality reduction is feature selection using various criteria. Traditional methods for feature subset selection in text categorization use an evaluation function that is applied to single words. All words are independently evaluated and sorted according to the assigned criterion. Then, a predefined number of the best features is taken to form the best feature subset. Scoring of individual words can be performed using some measure like, e.g., *document frequency* and *Information-theoretic term selection functions* (mutual information, information gain, χ^2 statistic).

In the paper [2] we explore the usability of the Oscillating Search algorithm [4] for feature/word selection in text categorization. We propose to use the multiclass Bhattacharyya distance for multinomial model as the global feature subset selection criterion for reducing the dimensionality. This criterion takes into consideration inter-feature relationships. We experimentally compare three subset selection procedures: the commonly used best individual feature selection based on information gain, the same based on individual Bhattacharyya distance, and the Oscillating Search to maximize Bhattacharyya distance on groups of features. The obtained feature subsets are then tested on the standard Reuters data with two classifiers: the multinomial Bayes and the linear Support Vector Machines [1]. The presented experimental results illustrate that using a non-trivial feature selection algorithm is not only computationally feasible, but it also brings substantial improvement in classification accuracy over traditional, individual feature evaluation based methods. We have shown that in text categorization tasks it is possible to achieve considerable classification accuracy improvement by employing a feature search procedure, that, unlike traditional approaches, evaluates feature groups instead of individuals. The most notable improvement is to be expected with subsets of lower sizes, where the time requirements of the discussed Oscillating Search procedure stay in reasonable limits. We have also shown that the multinomial Bhattacharyya distance is a good measure for both group-wise and individual feature selection, capable of identifying features that are good for conceptional different classifiers.

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Flexible-Hybrid Sequential Search in Feature Selection

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Among recent topics studied in context of feature selection the hybrid algorithms seem to receive particular attention. We propose a new paradigm of defining hybrid algorithms, and show one particular example – the flexible hybrid floating sequential search algorithm, that combines both the filter and wrapper search principles [3].

Filter methods for feature selection are general preprocessing algorithms that do not rely on any knowledge of the learning algorithm to be used. They are distinguished by specific evaluation criteria including distance, information, dependency. Since the filter methods apply independent evaluation criteria without involving any learning algorithm they are computationally efficient. Wrapper methods require a predetermined learning algorithm instead of an independent criterion for subset evaluation. They search through the space of feature subsets using a learning algorithm, calculate the estimated accuracy of the learning algorithm for each feature before it can be added to or removed from the feature subset. It means, that learning algorithms are used to control the selection of feature subsets which are consequently better suited to the predetermined learning algorithm. Due to the necessity to train and evaluate the learning algorithm within the feature selection process, the wrapper methods are more computationally expensive than the filter methods.

The main advantage of filter methods is their speed and ability to scale to large data sets. A good argument for wrapper methods is that they tend to give superior performance. Because of the success of the *sequential floating search* methods of filter type introduced by Pudil et al. [5] on many datasets and our focus on real-world datasets with potentially large number of features and small training sets, we have developed a *hybrid floating selection* algorithm that crosses the boundary between filter and wrapper methods and emphasizes some of the advantages of wrapper methods [7]. Similar principle of "hybridization" is outlined for other standard feature selecion algorithms as well.

The main benefit of the proposed algorithm is its ability to deal flexibly with the quality-of-result versus computational time trade-off and to enable wrapper based feature selection in problems of higher dimensionality than before. We show that it is possible to trade significant reduction of search time for negligible decrease of the classification accuracy. Experimental results are reported on two data sets, WAVEFORM data from the UCI repository and SPEECH data from British Telecom.

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Illumination Invariant Texture Retrieval

[1]Pavel Vácha, [2]Michal Haindl

Content-based image retrieval systems typically query image databases based on some colour and textural features. Optimal robust features should be geometrically and illumination invariant. Although image retrieval has been an active research area for many years this difficult problem is still far from being solved. Simpler methods based only on colour features achieve illumination invariance by normalising colour bands or using a colour ratio histogram. However colour based methods rarely perform sufficiently in natural visual scenes because they cannot detect similar objects in different location, illumination or backgrounds. Textures are important clues to specify objects present in a visual scene. Unfortunately the appearance of natural rough textures is highly illumination dependent. As a consequence most recent rough texture based classification or segmentation methods require multiple training images captured under a full variety of possible illumination conditions for each class. Such learning is obviously clumsy and very often even impossible if required measurements are not available.

We have presented methods that do not require neither mutual texture registration nor the knowledge of illumination direction. Moreover, they can be applied for textured objects retrieval if only single illumination training textured image for each class is available. The methods are based on a modelling of the texture gradients, which are computed over the Gaussian pyramid of the texture. The texture gradients are modelled using either causal simultaneous autoregressive model (CAR) or Gaussian Markov Random Field (GMRF). The both models use spatial correlation from neighbouring data. Finally, the feature vectors are composed of estimated model parameters, details can be found in [2].

The performance of the proposed methods have been tested in an illumination invariant texture retrieval and compared to steerable pyramid and Gabor features. The test set consits of bidirectional texture function (BTF) textures from the University of Bonn BTF database [1], where each texture is captured with 81 different illumination directions for a fixed view point direction. In the test we used single training image per class with unknown illumination direction. The view point direction was the same for all the texture images in the test.

The test results show that our methods were mostly able to find the correct texture class irrespectively of its illumination for all our experimental BTF textures and they outperformed the alternative methods. The proposed methods are invariant to the change of illumination brightness and we have also experimentally verified their robustness to illumination position variations. The additional advantage is that they are simultaneously robust to image degradation by the additive Gaussian noise. Furthermore, the proposed methods are fast and numerically robust so they can be used in an on-line image retrieval system.

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BTF Modelling using BRDF Texels

[1]Jiří Filip, [2]Michal Haindl

The highest fidelity representations of realistic real-world materials currently comprise Bidirectional Texture Functions (BTF). The BTF is a six dimensional reflectance function depending on view and illumination directions as well as on planar texture coordinates. The huge size of BTF measurements, typically in the form of thousands of sample images covering all possible combinations of illumination and viewing directions, has prohibited their practical exploitation and obviously some compression and modelling method of these enormous BTF data spaces is inevitable. Most of such methods [1, 2] is based on repetition of several BTF subsamples in planar space. However, this is hardly possible for structured irregular materials, e.g. wood. Finally a group of probabilistic BTF models was recently proposed [3, 4]. Although these methods reach huge impressive compression ratios and allow unlimited texture enlargement they sometimes compromise visual quality for certain materials.

The proposed approach combines BTF spatial clustering with cluster index modelling by means of efficient Markov random field model [5]. In contrast to sampling BTF enlargement methods the proposed approach allows to generate seamless cluster index of arbitrary size to cover large virtual 3D surfaces. The method starts with normal-map estimation of the underlying material surface using photometric stereo. The estimated normal-map $\mathbf{N}$ is enlarged to the required size using a probabilistic MRF model. In the following step the original BTF data are clustered in the spatial planar space. The results are cluster representatives $\mathbf{C}$ and cluster index $\mathbf{I}$, which is used for new cluster index $\mathbf{I}_S$ generation up to the required size of synthesised normal-map $\mathbf{N}_S$. This enlargement exploits matching between estimated $\mathbf{N}$ and synthesised $\mathbf{N}_S$ normal-maps and BRDFs at neighbouring spatial locations. Proposed matching scheme incorporates such effects as masking and occlusions and together with normals matching enable reliable and perceptually correct spatial ordering of individual clusters in new enlarged index.

The method represents original BTF data using a set of local spatially dependent Bidirectional Reflectance Distribution Function (BRDF) values. These BRDF texels are combined according to synthesised cluster index by means of Markov random field model. The methods strictly separates analytical (possibly off-line) part from the fast possibly real-time synthesis part of the whole modelling process. The BTF clustering allows to trade-off compression ratio and visual quality. The method shows the best performance for spatially random i.e. non-regular types of BTFs such as lacquered wood or leather, etc. The method enables fast seamless BTF data enlargement to arbitrary planar size with minimal additional storage requirements since the number of clusters is fixed. Despite providing compression ratio about 1 : 200 the proposed method preserves original reflectance dependently on illuminating and viewing directions for individual cluster centres (BRDFs). These BRDFs can be subsequently approximated by means of some standard empirical reflectance models to achieve even higher BTF compression ratio. Moreover, the proposed approach allows fast BTF rendering at interactive frame-rates.

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Process model optimalization

[1]Vladimír Vaněk, [2]Petr Lukasik

In this presentation we will show current status of our research of methods for optimalization business process model.

As business process model were chosen hierarchic time Petri nets. Advantages and disadvantages of this model will be on topic as well. This model is still just the starting point for out main intention optimalization of business process model.

Based on this model we are dealing with different types and ways of optimalization, namely soft computing optimalization that could be used in case of uncertainty and conventional optimalization in when we have good level of certainty.

Two methods that seem to be most interesting will be presenting

1^{st} is based on Theory of Constraints which is very popular and demanded in production and service organization. This method is very intuitive to understand and very usable when we have good level of certainty. The Theory of Constraints (or TOC as it is called) is a relatively recent development in the practical aspect of making organizational decisions in situations in which constraints exist. The theory was first described by Dr. Eliyahu M. Goldratt in his novel, The Goal

2^{nd} method use fuzzy logic for dealing with different levels of uncertainty. This method could be used as well with combination with 1st method for far seeing predictions.

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Using fuzzy Petri nets for process definition

[1]Jaroslav Knybel, [2]Viktor Pavliska, [3]Jaroslav Procházka

The new approach in information system automation is process or workflow management. For unskilled user is important, when the business processes of company are described. Then, according to this description are users led correctly in their work. The business (application) model can be caught in finite state machines and its variations. Petri net can be used for process definition in process wizard. Sometimes unclear state occurs, for its description can be fuzzy logic IF-THEN rules used. Our aim is to define tool for modeling business processes with possibility of modeling vague processes using fuzzy Petri nets in QI information system. This paper describes current aims and our results

Today's open global market changes the nature of business. Company that wants to be able to compete must leave traditional organization structure and not convenient leading methods. Company should be focused on customer and should be managed by market requirements. From an inner point of view, company should focus on processes and team cooperation. The base of all these changes is the use of (new) information technologies. The processes are the roots of every working organization. Modern organization that wants to be able to compete on market in global society should be based on automation processes. In recent state the process support in information systems is not spread. There exist several solutions on the market, where user can define company's processes and these definitions join with information system's functions. Such system can show, what was previous process step or user can see possible following steps according to current process state. One of these tools is IS SAP and process tool ARIS, other one is e.g. Baan IS. QI IS also contains support for process management. Unfortunately process or process participants can include elements that are not clear. When we use strict process definition, we are not able to capture these elements. One approach how to include unclear elements into process description is the use of fuzzy approach.

It is possible to describe application domain or process transitions using finite state machines (FSM). They are strictly formal and have mathematical apparatus, thus they are suitable for process modeling, simulation and automatic generation. Although FSM is really spread, it has several limitations, namely parallelism modeling, distribute system modeling and huge state amount for complex process description. Consequently another formalism based on FSM is used: Petri nets.

As said, we can extend Petri net concept with unclear (fuzzy) elements for the purpose of process modeling. Our approach includes fuzzy logic by following way. Token holds fuzzy set definition, arcs are evaluated by natural language expressions and finally transitions represent fuzzy relation corresponding to given IF-THEN rule. To be more precise, we must say that whole Petri net is decomposed into several groups of related rules. Each group of rules forms rulebase which corresponds to one LFLC unit. These units are interconnected on higher level of abstraction and whole system forms Linguistic Fuzzy Logic Net (LFLN).

We use Petri nets as a formal visual tool for process modeling. Using fuzzy Petri net is possible to shift decision making on system in some cases. That is the reason, why we include fuzzy Petri net into process modeling tool. We also use designed tool for application parts generation, but this is out of the scope of this paper. This year aims were final definition / extension of QI information system data model to use it for storing fuzzy Petri net and mapping Petri net elements to data model (together with the storing of vague values).

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2^{nd} International Workshop on
Data - Algorithms - Decision Making

Session 4.

December 11, 2006, Afternoon
Chairman: Jan Flusser

Some Methods of Robot Movement Control

[1]Ondřej Polakovič

Our problem is to control movement of robot. By a robot we mean a moving autonomous vehicle which moves within a chosen corridor with a constant speed. It should successfully move through chosen continuous corridor without obstacles. In this contribution we show some approaches to solve this problem.

First approach is based on classical (crisp) if-then rules, second approach is based on fuzzy if-then rules and extended transform [1, 2], third approach is based on fuzzy if-then rules and perception based logic deduction. Fourth approach is based on neural network and backpropagation algorithm [4, 5]. All of these methods are able to control robot and its movement successfully [3]. The methods was verified on various corridors. Moreover we have used learning vector quantization to classify various types of corridors.

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Fuzzy Transforms - a New Basis for Image Fusion

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Image fusion aims at integration complementary multiview information into one new image with the best possible quality. The term "quality" depends on the demands of specific application. Mathematically, if u is an ideal image (considered as a function with two variables) and $C_1 \dots C_N$ are acquired channels then the relation between each C_i and u is expressed by $C_i(x,y) = D_i(u(x,y)) + s_i(x,y)$, where D_i is an unknown operator describing the image degradation and s_i is an additive random noise. To fuse images from channels means to obtain an image $\hat{u}$ which gives in some sense better representation of u than each individual channel C_i. Different fusion methodologies are influenced by peculiarities of degradation operators D_i, see [**?**] for details.

In this contribution, we assume that every point (x,y) of the image is assumed to be acquired undistorted in (at least) one channel. Image fusion then consists of comparing the channels in image domain, identifying the channel in which the pixel (or the region) is depicted undistorted and, finally, of combining the undistorted parts.

To find the undistorted channel for the given pixel, we propose to use components of the ordinary fuzzy transform as a focus measure. The reason is that components of the F-transform (integral or discrete) being the *weighted mean values* of an original function are close to zero over a distorted part. Therefore, fusion of images from channels is performed iteratively by merging inverse F-transforms of C_i and choosing that F-transform component which has a maximal absolute value.

Let us briefly overview the procedure: The main task is to find a formula using which we may express original function $f : X \to Y$ (represents a particular image) with an arbitrary precision, in our case, to expand f so that $f(x) = \sum_{i=0}^{\infty} fi(x)$. Then we may transform functions $f_1 \dots f_p$ and operate on each level $i \in \mathbb{N}$

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Applications of Fuzzy Modeling

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Fuzzy modeling is area, which has a lot of use in this time. The control is one of them. A process of the control is usually described by a complicated mathematical description, for which the classical control is not possible suggest. In this case, the controller must be simplified or an approximated method must be used. Sometimes estimated values are only given (for example rainfall forecast). Therefore truth of the classical control is not guaranteed. For the described cases the fuzzy control is suitable because an approximated notion of process behavior is sufficient (see in [1]).

The contribution will introduce two control systems. First one is the simple control of water level in a cylinder vessel. The PI control system is used there. Software LFLC 2000 (linguistic fuzzy logic controller) which has been developed by Institute for Research and Applications of Fuzzy Modeling in Ostrava University was applied for numerical realization. For the sake of simplicity a constant inflow is supposed. The aim is to find demanded height of level in the vessel. Further, the model is generalized such that changes of the fuzzy controller are not done in every time step.

The second control is more complicated. It deals with operative management of reservoir water discharge during the flood passage using the PI control LFLC 2000. Inflow is changeable and a value of outflow is demanded.

Other problem, which is introduced there, is coral reef growth. In this problem was processed historical data. The Fuzzy Transform method (see in [2]) was used to solving complicated differential equation (see in [3]) that describes growth of reef. The animation process is created there.

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Mining Linguistic Associations from Data Using LFLC

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In this contribution we present a method of data mining which is under development in our institute [3]. The main idea is to evaluate real-valued data by the corresponding linguistic expressions and then search for the corresponding associations using some of the standard data-mining techniques (we have used GUHA method).

Associations, which are mined by this technique have form of sentences of natural language. Hence we call them *linguistic associations*. A typical form of linguistic association is

> *IF profit is high AND cost is rather low THEN productivity is very high AND volume of sale is significantly large.*

Our method captures the genuine linguistic meaning of such associations. This is achieved using a formal logical theory which provides a mathematical model of meaning of evaluating linguistic expressions (a certain class of natural language expressions).

In the first phase of our method, numerical data are replaced by linguistic expressions. It creates a new data table which contains the most suitable linguistic expressions with respect to original numerical data. Then, GUHA method [2] is used on this new data table.

The main outcome of linguistic associations in their easy (or, at least, easier) understandability for the user, in the possibility to use their logical properties for significant reduction of their number, and also in the fact that their vague meaning enables less strict interpretation which complies with the uncertainty of existence of a relation characterized by them.

Mining of linguistic association was implemented in the frame of LFLC 2000 (Linguistic Fuzzy Logic Controller) [1]. The main purpose of this software system (developed in our institute) is to enable the design of linguistic descriptions (sets of IF-THEN rules which contain evaluating expressions) and to work with them. It also solves related tasks, e.g. learning of linguistic descriptions from data, reducing the number of IF-THEN rules in linguistic descriptions, testing the behavior of these descriptions etc.

We tested our method on several data sets from various fields (economy, traffic) using LFLC software. The results are promising. However, the issue of computational complexity should be addressed and testing on larger data sets would be also important.

We will present some theoretical background of this method (evaluating linguistic expressions, GUHA method) and discuss the implementation in LFLC and results of this method on various data. We will also mention related method which uses *fuzzy transform* [4].

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A survey of the recent work on image analysis in UTIA

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In 2006, we focused our attention not only on theoretical research but also on several applied projects. Theoretical part consisted namely of further development of superresolution imaging [1], multichannel deconvolution with constant kernels [2, 3], multichannel deconvolution with variable kernels along with the scene depth recovery [4], multifocus image fusion by means of regularized decision maps [5], image fusion for precise object identification [6], and recognition of deformed and incomplete objects by geometric invariants [7, 8].

The aim of our applied research was to develop sophisticated user-friendly applications that would use our previous theoretical results and that would be able to help the users with resolving their domain problems. We concentrated on three particular areas.

Resolution enhancement of digital images captured by a low-cost camera: This application has been developed in collaboration with the Inst. of Optics, CSIC, Madrid, Spain, and the University of Oulu, Finland. The motivation came from producers of cell phones and low-cost cameras. We created a Matlab Toolbox including user interface and manual , which is now being tested in the Inst. of Optics and at the University of Oulu. This software is able to remove blurring, shaking, and to increase the spatial resolution up to factor 2.

Image processing and retrieval system for microscopic images of art specimens: This application has been developed in collaboration with the Academy of Fine Arts, Prague. We developed database system Nephele [9], which comprises image preprocessing, segmentation of different layers, and retrieval-by-example capability.

Biomedical applications: We have been active in several biological and medical applications, namely in modelling of human vision defects [10] and in analysis and monitoring microscopic specimens [11] (jointly with the Palacky University, Olomouc).

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Superresolution Imaging - Live Demo

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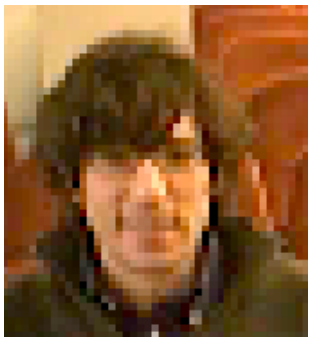
Imaging plays a key role in many diverse application areas, such as astronomy, remote sensing, microscopy or tomography, just to name few. Due to imperfections of measuring devices (optical degradations, limited size of CCD sensors) and instability of observed scenes (object motion, media turbulence) acquired images are blurred, noisy and may exhibit insufficient spatial and/or temporal resolution.

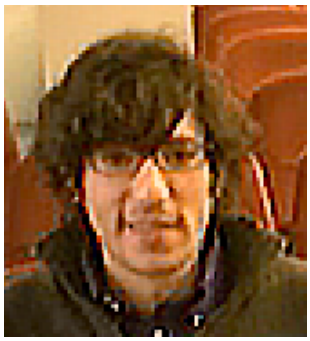
In order to recover the original image, we need techniques called blind deconvolution and superresolution that remove blurs and increase resolution, respectively. A necessary condition for the methods to be stable is to have more than one image of the scene (multiframe imaging). These images must be different to provide new information. However, the differences can be almost imperceivable, e.g., subtle spatial shifts or a slight modification of acquisition parameters (focus length, aperture size).

Current multiframe blind deconvolution techniques, such as [1], require no or very little prior information about the blurs and they are robust to noise to give satisfactory results in most of the real applications. Nevertheless, they can hardly cope with low-resolution images since in this case a standard convolution model is violated. On the contrary, state-of-the-art superresolution techniques proposed e.g. in [2, 3] achieve remarkable results in resolution enhancement by estimating the subpixel shifts between images but lack any apparatus for calculating the blurs. The superresolution methods either assume that there is no blur or that it can be estimated by other means.

We propose a unifying system that simultaneously estimates blurs and the original undistorted image, all in high resolution, without any prior knowledge of the blurs or original image; [4]. We accomplish this by formulating the problem as constrained least squares energy minimization with appropriate regularization terms, which guarantees close-to-perfect solution in the noiseless case.

Blind superresolution will be demonstrated on webcamera live video sequences and attendees can expected results similar to below. The left image shows one low-resolution frame from a webcamera video. Using 10 consecutive frames from the video, we are able to estimate a high-resolution image on the right.





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Nephele: Electronic database of materials research of paintings

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We introduce comprehensive solution for processing and archiving information about artwork specimens used in the course of art restoration - *Nephele*. The information processing based on image data is used in the procedure of identification of pigment and binder present in the artwork, which is very important issue for restorers [1]. Materials research is usually provided as a part of restoration process. The aim of the materials research of painting layers is to identify inorganic and organic compounds (pigments and binders) using microanalytical methods, and to describe stratigraphy and morphology of layers in light end electron microscopes. The results are used to interpret the painting technique of original paint and re-paints and to describe secondary changes of painting materials. The materials research report usually contains images, texts and analytical data. For the future comparisons, historical evaluations, dating, and authentication, the comprehensive electronic database of all these results would be very helpful.

The *Nephele* system is the database system for painting materials research reports, extended with the image preprocessing modules and the image retrieval facility. A report contains general information about the artwork, its author, and used art technique. The information about each studied specimen from the artwork with its localization is included, along with all undertaken analyzes and their results, with estimated color layers and used materials. All taken images are included (for example visual spectra, UV, and electron microscope images, to name the most usual).

The implemented digital image processing methods enable acquired data preprocessing for further analyzes as well as improve the querying above the reports database. The preprocessing of VS and UV specimen images, used for the identification of pigment and binder present in the artwork, consists of image registration and segmentation technique. The image registration makes use of the mutual information approach because of the multimodal nature of the data. It removes the geometrical differences between the VS and UV images of the specimens introduced during the image acquisition. The following segmentation based on the modified k-means clustering produces preliminary detection of present color layers.

In the archiving part of the *Nephele*, our research concentrated on enabling easy access to archived data. For such database of painting materials research reports, the look-up of archived reports based only on the text information is often not enough. The ability to fetch reports which describe visually similar specimens/materials can increase the helpfulness of the database. However, such a task is very difficult for a human operator without proper software help. In addition to the traditional database functions (text-based search, archiving), we have incorporated image-based retrieval methods into the developed system [2]. They are based on the feature descriptions of the specimen images, which are represented using the Haralic descriptors of co-occurence matrices together with the color descriptors in the VS+UV case, in the case of SEM images the wavelet decomposition and the energy of its high frequency subbands was applied. Presented examples of achieved results show the applicability of the system.

All work was realized in close cooperation with the experts from Academic Laboratory of Materials Research of Paintings, joint workplace of the Academy of Fine Arts in Prague and Institute of Inorganic Chemistry AS ČR. More information can be found in [3].

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Overview of Biomedical Image Processing Activities of Brno Group of the DAR project

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The Brno group of the DAR project is a part of the image processing group lead by Prof. J. Flusser, Inst. of Information Theory and Automation, Cz.Ac.Sci, Prague. Besides being involved in general image processing theory and applications, the group deals with the following particular projects:

1. Processing of image data in ultrasonic computed tomography (USCT), in cooperation with the ForschungsZentrum Karlsruhe (Germany) where the experimental system has been set up. The group is involved in:
   (a) experimental image reconstruction methods, particularly as the attenuation image reconstruction concerns [2]
   (b) effective implementation of the reconstruction algorithms in parallel processing environment, including building distributed parallel environments based on of PC computers (clusters) [6]
   (c) restoration of the obtained images taking into account the nature of the acquisition
   (d) computation based calibration of the measuring USCT system [5]
   (e) simulation of ultrasonic fields with the aim to improve the understanding of the image data acquisition and calibration processes [7]
2. Image analysis of medical images particularly in ophthalmology with the aim of early glaucoma diagnosis, in cooperation with the University AugenKlinik Erlangen (Germany) and Ophthalmological Clinic in Zlín (Czech Rep.). Particular interest is paid to
   (a) multimodal flexible image registration based on mutual information criterion, followed by image fusion [1]
   (b) detection and segmentation of particular areas in retinal images, e.g. optical nerve disc, autofluorescence areas, neurofiber layers etc. [1] [2]
3. Investigation of the possibilities of sight improvement in patients impaired by unsuccessful laser ablation operations. This project is still in its infancy; the experimental optical and computing set-up is being developed.

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Ultrasound Transmission Tomography Using Algebraic Reconstruction Techniques

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Ultrasound transmission tomography is a potentially promising alternative to standard X-Ray imaging in medical diagnosis, especially in mammography. The reconstruction of the local attenuation coefficient from the measured signals can be formulated as a large overdetermined system of linear equations based on a simplified ultrasound transmission model.

There are several methods of solving such overdetermined systems, eg. *least squares method* or various minimisation techniques. In our work we focus on the *Kaczmarz algebraic reconstruction technique*[1]. The algorithm employed by the technique successively iterates through the equations and computes the corrections of the initial solution estimates. This makes the technique suitable for solving large systems which cannot fit into the computer memory.

Since we cope with an inconsistent system of equations that is obtained from noisy data, the original version of the algorithm does not guarantee convergence to the optimum. Therefore, we employ an extended version of the technique which first successively iterates through the columns of the system matrix and computes the corrections of the right-hand-side vector. The extended method has been shown previously to converge to the least-mean-squares optimum [2].

Both the original and extended algorithms are strictly sequential, since the computation in the particular iteration depends on the corrections from the previous step. To enable parallelisation of the method, thus speeding up the computation, the system is partitioned into blocks of equations and each block is processed separately. More precisely, the corrections are iteratively computed inside each block as in the sequential version starting with the same initial estimate. However, there is no data interchange among the blocks during the computations. This results in multiple corrections corresponding to each block which are at once applied to the initial estimate. Since each block is processed independently, the behaviour of the technique, i.e. the accuracy as well as the convergence can be substantially affected.

The partitioning scheme was implemented for the original as well as the extended Kaczmarz method and the implementation was tested on both synthetic and real radiofrequency data acquired using an experimental tomograph [1]. During the testing, accuracy of the computed results and the speed of the convergence were measured with respect to the number of blocks increasing from one (no partitioning) up to 64.

In both cases the partitioning leads to a considerable speed-up of the computation (up to 26× for the original method and 3× for the extended method). The partitioning is meaningful up to a certain number of partitions (about eight), for more partitions, the speed does not increase any more. The partitioning of the system also positively affects the accuracy of the original Kaczmarz method. On the other hand, the accuracy of the extended Kaczmarz method is not affected by the partitioning. The extended Kaczmarz method had superior accuracy over the original method.

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Analysis of Retinal Autofluorescence Images for Early Glaucoma Diagnosis

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Introduction
The glaucoma is a significant cause of early blindness. There are many methods for its detection including perimetry, intraocular pressure measurement and also some high technology imaging methods. One of these methods is laser scanning based techniques. There are several laser scanning devices measuring various tissue properties. One promising technique for early glaucoma diagnosis is based on detection of autofluorescence light from retinal tissue. The imaging device that measures this emission is Heidelberg Retina Angiograph [3] that enables to acquire high resolution retinal images in several modes. We are interested only in autofluorescence (AF) and infrared (IR) images, because there are assumptions that in a case of high intraocular pressure, the AF images may contain small isles exhibiting higher level of autofluorescence around the optical disc (OD). Its area and distance from optical disc are important parameters for glaucoma diagnosis [4].

Method
The proposed algorithm for AF isles detection is as follow:

1. Detection of the OD is performed in IR images, because of the high contrast between inside and outside OD area. After manual localization of the OD center and approximation by circle, the spline active contour is used to adjust a fine OD border [1].
2. The AF and IR images are registered in order to obtain a transform T (including rotation, translation and scaling). Normalized correlation and controlled random search with multiscale approach is used [1].
3. The OD border is mapped from IR to AF image through transform T.
4. The region of interest is determined.
5. The segmentation based on the region growing is applied using the image gray level. The seed point is determined manually and new pixel is added based on simple criteria

$$(RegionMeanValue - CurrentPixelValue) < Threshold$$

where RegionMeanValue is changing after each iteration after new pixel is added.

Evaluation
There is no golden standard method for comparison; therefore the only way to evaluate the results is to use manually segmented images that we have in our database of 20 images (512x512 or 1024x1024 pixels). Each image was segmented by three physicians and the areas of AF isles were determined. High inter-operator variability was observed in this segmented data. That makes the semiautomatic segmentation reasonable approach to decrease this variability. The results are promising and show an acceptable area approximation of the manually segmented areas.

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MUDIM - a software tool based on MUltiDImensional Models

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Ability to represent and process multidimensional probability distributions is a necessary condition for application of probabilistic methods in Artificial Intelligence. Most popular approaches to solve this task are based on Graphical Markov Models (GMM - [6]), from which Bayesian Networks (BN - [2]) are most often used. In the present contribution we will deal with an alternative to GMM, so called Compositional Models (CM - [3, 4]), and present state of art of both MUDIM development and the corresponding theory of Compositional models. The basic idea of these models resembles jig-saw puzzle, where a picture must be assembled from a great number of pieces each bearing a small part of a picture. Analogously, compositional models of a multidimensional distribution are assembled (composed) from a great number of low-dimensional distributions.

MUDIM has been created with the goal to gain a simple but powerful tool for experimental computations with compositional models. This tool is implemented as an additional package of the R language environment. This makes from MUDIM rather powerful tool, which enables the users to code their own procedures with the help of a large collection of different functions integrated in R environment as well as with the help of the following basic MUDIM functions realizing the most important operations:

- distribution and model construction
- computation of Kullback-Leibler divergence, Information value and Entropy of distributions.
- computation of marginal distributions
- marginalization of a model in different ways
- perfectization of a model

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An Algebraic Approach to Structural Learning Bayesian Networks

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The procedures for learning *Bayesian network* (BN) models can roughly be divided into two basic groups. Some of the algorithms are based on significance tests, that is, statistical *conditional independence* (CI) tests. The second basic group of algorithms consists of the procedures based on the maximization of a suitable *quality criterion*. The algorithms of this kind became popular in recent years. The present contribution deals with structural learning based on the maximization of a quality criterion by the *local search method*.

Its goal is to present briefly an algebraic approach to this special learning method. It brings surprisingly clear perspective on the method, which can possibly be extended to a structural learning method for general CI models. Actually, the presented algebraic approach is an attempt to apply a general algebraic method for describing probabilistic CI structures from [5] to learning BN models. The basic idea is that every BN model – that is, the class of distributions satisfying the CI restrictions determined by an acyclic directed graph – can be represented by a certain vector, whose components are integers, named a *standard imset*. This vector is uniquely determined representative of the BN model, like the well-known essential graph. The standard imset corresponding to an acyclic directed graph G will be denoted by u_G.

The common criteria used in practice in the local search method typically satisfy two basic requirements: they are *score equivalent* and *decomposable*. These two requirements imply together that the criterion is necessarily a shifted linear function of the standard imset. More precisely, provided $\mathcal{Q}$ is a quality criterion of this kind, it has the form

$$\mathcal{Q}(G,D) = s_D^{\mathcal{Q}} - \langle t_D^{\mathcal{Q}}, u_G \rangle \,,$$

where G is a graph, D a database, $\langle x,y \rangle$ denotes the scalar product of vectors x and y, $s_D^{\mathcal{Q}}$ is a real constant and $t_D^{\mathcal{Q}}$ a vector depending on the database, called the *data vector* (relative to $\mathcal{Q}$). Thus, all substantial information about the database is involved in the data vector and the problem of maximization of $\mathcal{Q}$ is transformed to the problem of maximization of a linear function (determined by $t_D^{\mathcal{Q}}$) on a finite set of vectors, namely on the set of standard imsets.

Standard imsets are appropriate to testing of the inclusion of BN models. Two BN models are in inclusion iff their differential imset is a combination of elementary imsets, named a *combinatorial imset*. Note that the question of computer testing whether a given vector is a combinatorial imset is very close to the problem of computer testing CI inference dealt with in [2]. Altogether, the algebraic approach leads to a proposal to modify the local search method so that some linear programming algorithms could be utilized in the future.

The presented algebraic view can also be naturally extended to databases: if a criterion $\mathcal{Q}$ of the above mentioned kind is fixed then every database can be represented in the form of a *data vector* (relative to $\mathcal{Q}$), which is a vector of the same dimension as the standard imset.

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Additive decomposition of probability tables

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We propose a new additive decomposition of probability tables - *tensor rank-one decomposition* [1]. The basic idea is to decompose a probability table into a series of tables, such that the table that is the sum of the series is equal to the original table [3]. Each table in the series has the same domain as the original table but can be expressed as a product of one-dimensional tables (i.e., it has rank one).

Entries in tables are allowed to be any real number, i.e. they can be also negative numbers. The possibility of having negative numbers, in contrary to a multiplicative decomposition, opens new possibilities for a compact representation of probability tables. Tensor rank-one decomposition can be used to reduce the space and time requirements in probabilistic inference. We provide a closed form solution for minimal tensor rank-one decomposition for some special tables and propose a numerical algorithm [2] that can be used in cases when the closed form solution is not known.

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Shapley Mappings and Values of Coalition Games

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A time-honored concept of Shapley value [5], which describes a fair distribution of profit among players in a cooperative game, was generalized in various ways depending essentially on the definition of fairness, a number of players involved, a type of coalition structures, and a class of games considered. Aumann and Shapley [2] initiated the study of games with coalitions to which their members belong to a certain membership degree (so-called fuzzy coalitions); games with fuzzy coalitions (so-called fuzzy games) are investigated systematically in [1] and [3]. The presented contribution focuses on fuzzy games in which the worth of every fuzzy coalition results from aggregating the worth of players on each level that is weighted with a possibly distorted degree of membership corresponding to the level. The distortion function is subject only to a condition that players totally participating in a fuzzy coalition must be considered with the full degree of membership, and, analogously, players who do not participate in a fuzzy coalition at all must be considered with zero membership degree.

The ideas sketched above are captured by the mathematical model elaborated in the authors' paper [4]. Let $N = \{1, \dots, n\}$ be a finite set of players. A fuzzy coalition is a vector $A \in [0,1]^N$ and $\mathcal{F}$ denotes the set of all fuzzy coalitions. A function $\psi : [0,1] \to \mathbb{R}$ satisfying $\psi(t) = 0$ iff $t = 0$, and $\psi(1) = 1$, is called a weight function. A fuzzy game is a mapping $v : \mathcal{F} \to \mathbb{R}$ with $v(\emptyset) = 0$. We denote by $\mathcal{G}[\psi]$ the set of all fuzzy games v such that $v(A) = \sum_{t\in[0,1]} \psi(t)v(A_t)$, for every $A \in \mathcal{F}$, where $A_t := \{i \in N : A(i) = t\}$, $t \in [0,1]$. A *Shapley mapping* is a linear mapping $\mathbf{\Phi} : \mathcal{G}[\psi] \to (\mathbb{R}^N)^{\mathcal{F}}$ preserving the condition of coalitional efficiency, the non-member, and the symmetry axiom. It turns out that these requirements already uniquely determine a Shapley mapping $\mathbf{\Phi}$ associating to every fuzzy game $v \in \mathcal{G}[\psi]$ and to every fuzzy coalition A a vector $\mathbf{\Phi}(v)(A) = (\mathbf{\Phi}_1(v)(A), \dots, \mathbf{\Phi}_n(v)(A))$, which can be thought of as an analogue of Shapley value [5] extrapolated to fuzzy coalition levels. The expected total allocation $\Phi_i(v)$ of player i in the cooperative process is considered as a (Lebesgue) integral $\Phi_i(v) := \int_{\mathcal{F}} \mathbf{\Phi}_i(v)(A)dA$ over the set of fuzzy coalitions $\mathcal{F}$ and the total pay-off vector $\Phi(v) := (\Phi_1(v), \dots, \Phi_n(v))$ is called a *cumulative value.* It is proven in [4] that if the weight function ψ is bounded and (Lebesgue) integrable, then the cumulative value $\Phi(v)$ is well defined and $\Phi_i(v) = v(\{i\}) \int_0^1 \psi(t)dt$, for each $i \in N$. The allocation scheme underlying the Shapley mapping is thus a procedure through which each player re-evaluates his personal worth by taking into account the weight of his membership degrees to fuzzy coalitions. Along this procedure a weight function ψ with $\int_0^1 \psi(t)dt > 1$ favors players i with positive individual worth $v(\{i\})$, while a weight function ψ such that $\int_0^1 \psi(t)dt < 1$ favors players with negative worth $v(\{i\})$.

The function $v \mapsto \Phi(v)$ is a *semi-value* on $\mathcal{G}[\psi]$ since it has the null-player property, it is symmetric and linearly dependent on v. Moreover, on the linear subspace of $\mathcal{G}[\psi]$ consisting of all games with the property $\left(\sum_{i\in N} v(\{i\})\right) \int_0^1 \psi(t)\ dt = v(N)$, the cumulative value is also efficient, that is, $\sum_{i\in N} \Phi_i(v) = v(N)$, and the function $v \mapsto \Phi(v)$ is then a *value.*

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Applications of the Rényi divergences in testing hypotheses about exponential models

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Let $\mathfrak{X}$ be a metric observation space with the Borel field $\mathcal{A}$ of events and μ a σ-finite measure on $\mathcal{A}$. A family $(P_\theta : \theta \in \Theta)$ of probability measures on $(\mathfrak{X}, \mathcal{A}, \mu)$ indexed by a parameter θ from an open set $\Theta \subset \mathbb{R}^k$ is called the *natural exponential family* if for every $\theta \in \Theta$

$$P_\theta \ll \mu \qquad \text{and} \qquad f_\theta(x) = \exp\{\theta^T A(x) - \kappa(\theta)\} \tag{1}$$

where f is the Radon-Nikodym derivative $\frac{dP_\theta}{d\mu}$. Here A is a measurable mapping from $\mathfrak{X}$ to $\mathbb{R}^k$ and κ is a convex function from Θ to $\mathbb{R}$.

The maximum likelihood estimator of parameter θ for this model is well known. We are interested in testing hypotheses about parameter θ and we employ here so called *Rényi statistics* as test statistics. The Rényi statistics are derived from the generalised Rényi divergences and the maximum likelihood estimator. The Rényi divergences of orders $r \in \mathbb{R}$ for probability measures P_1, P_0 with densities f_1, f_0 were introduced by Liese and Vajda [1] and are given by formulas

$$D_r(P_1, P_0) = \frac{1}{r(r-1)} \ln \int f_1^r f_0^{1-r}\, d\mu \qquad \text{for } r \neq 1, r \neq 0,$$

$$D_1(P_1, P_0) = D_0(P_0, P_1) = \int f_1 \ln \frac{f_1}{f_0}\, d\mu.$$

The test of a hypothesis then follows from a limit behaviour of Rényi statistics T_r which was proved by Morales et al. for simple hypotheses in [2] and for composite hypotheses in [3]. Since there is the whole set of statistics $\{T_r : r \in \mathbb{R}\}$ the testing must include a selection of a suitable one. It usually has two steps: first, a choice of a proper finite subset $\mathcal{R} \subset \mathbb{R}$ of orders for which the test is constructed, second, an optimisation based on the true test power which selects the most suitable statistic from $\{T_r : r \in \mathcal{R}\}$.

We focus on the case of dependent observations which comes from a realisation of a time-continuous stochastic process $(X_t : t \geq 0)$. In this case, $(\mathfrak{X}, \mathcal{A})$ is the space of right continuous functions having left limits (càdlàg functions) from $[0, \infty)$ to $\mathbb{R}$ equipped with a filtration $(\mathcal{A}_t)_{t \geq 0}$. Family $(P_\theta : \theta \in \Theta)$ of probability measures on $(\mathfrak{X}, \mathcal{A})$ is called the *exponential family of processes* if for every $\theta \in \Theta$

$$P_\theta \restriction_{\mathcal{A}_t} \ll \mu \restriction_{\mathcal{A}_t} \qquad \forall t \geq 0$$

and if for every $t \geq 0$ density $\dfrac{dP_\theta \restriction_{\mathcal{A}_t}}{d\mu \restriction_{\mathcal{A}_t}}$ is expressed by

$$f_\theta(\mathbb{X}_t) = \exp\{\theta^{\mathrm{T}} A_t - \kappa(\theta) S_t\}$$

where $\mathbb{X}_t \in \mathfrak{X} \restriction_{\mathcal{A}_t}$ denotes a path up to time t, A_t is a k-dimensional càdlàg process $\mathcal{A}_t$-adapted, κ is a convex function from Θ to $\mathbb{R}$ and S_t is a non-decreasing continuous stochastic process such that $S_0 = 0$ and $\lim\limits_{t \to \infty} S_t = +\infty$ a.s.(P_θ) for every $\theta \in \Theta$. Note that many well known Markov processes like diffusion processes and counting processes are examples of such an exponential family.

The aim of this contribution is to demonstrate these techniques for testing hypotheses on one particular example and illustrate a wide class of statistical experiments for which it can be applied.

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Hierarchical and Distributed Urban Traffic Control

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The traditional way of controlling urban traffic is using centralised control approaches: There is a single control centre where decisions are made about the traffic control in the whole urban area. Currently, this paradigm is being replaced by more decentralised hierarchical approaches with smaller control centres serving sub-regions of the intersection network in a city. Possible future development in this area is the use of distributed or multi-agent systems in the form of peer-to-peer networks of decision-makers [1, 4, 2].

The presentation will overview software aspects of two promising approaches at different maturity level that are being developed at UTIA in the scope of the DAR research centre, namely a *hierarchical controller for urban traffic control* and a *single-level distributed approach using Bayesian agents*.

The hierarchical traffic controller divides the regulated area into several microregions where traffic signals are set and coordinated in order to maximise the number of vehicles passing through the network. For testing the method we use different kinds of filtering (mostly Kalman and Kalman DD1 filters) and we may use different model and control plugins. In order to assess the performance of the controller, the whole system is able to communicate with a microscopic traffic simulator and with a prototype of a real intersection controller that would be normally used to set the traffic signals.

The distributed traffic controller based on Bayesian traffic agents [3] extends the previous work on a deterministic traffic model for the distributed Bayesian decision-making paradigm. The main idea behind this approach is based on observation that surface traffic in urban areas is a typical example of a system with strong presence of uncertainty and the need for decentralized controllers. In this case the traffic control is carried out by *traffic agents* designed using the theory of distributed Bayesian decision-making. These agents optimise the local traffic on a single intersection while receiving predictions of future trends as probability density functions and negotiating the optimum settings with their neighbours using probability calculus.

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Linear Uniform State-Space Model of Traffic Flow and its Estimation

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State estimation is an important subtask of a range decision making problems. Kalman filtering (KF) [3] is the first-option method for its addressing. However, still there is no well-established methodology of selecting innovation covariances. Also, it is difficult to combine KF with hard restrictions on state ranges. Both these drawbacks can be avoided by assuming that the model innovations are uniform.

In this contribution, state-space model with uniformly distributed innovations is introduced and the Bayesian state estimation proposed, [2]. This extends parameter estimation of the controlled autoregressive model treated in [1]. Similarly as in the latter case, the off-line evaluation of the maximum a posteriori probability (MAP) estimate of unknowns in the linear state-space model with uniform innovations reduces to linear programming (LP). The solution provides either estimates of the noise boundary and parameters or of the noise boundary and states.

The on-line estimation is obtained by applying LP on the sliding window, i.e., by considering only the fixed amount of the newest last data and states items.

Joint parameter and state estimation is obtained either by swapping between state and parameter estimations or by use of Taylor expansion for approximation of products of unknowns.

The introduced model is prepared to be used in transportation data processing. Here, the length of queue on an intersection arm is the unknown system state which is estimated. The greens on the traffic lights compose the inputs and the output intensities (in cars per time period) are the output data.

An illustrative example will be presented.

The main current contributions of the introduced model include feasible care about hard bounds of estimated quantities; joint estimation of parameters, state, and noise boundaries; parameter tracking via windowing the joint estimation.

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Urban Traffic Control Model

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Modern and economic development of contemporary towns is without question highly dependent upon traffic infrastructure progress. Automobile transport intensity is dramatically rising in large towns. At the same time number of traffic congestions and accidents is increasing, standing times are becoming longer and ecological stress is also escalated. This entire means traffic service level systemic upset. To solve this situation seems to be the most effective solution to design intelligent traffic light intersection control system. This control system should improve permeability of traffic road network with a respect for all demands on recent trends of traffic development in towns and regions.

For the real-time traffic control in towns in two ways of controlling are used: with a centralized intelligence and with a decentralized intelligence. The centralized intelligence of control monitors all data from detectors in the area in the real time. The control parameters are changed on bases calculation of cars propagation in the town network. The second way is the decentralized intelligence of control, where the traffic intersection point responds directly on states of traffic and the control computer as function of co-coordinator individual intersections in the network is on the higher level. This way of control collects data from all detectors and traffic situation is changed cycle time, structure of stages or green time according to momentary. More traffic light controls are grouped to areas in town. Areas are organized in linear or areawide control in time scale from 5 to 15 minutes.

Intelligent traffic system is tendency suggest and implementation so that is responded automatically to traffic incident as are accidents, congestion, special states of other technology, traffic restriction etc. For system realization is necessary to suggest suitable algorithm of control, which one will be used as module in the traffic centre of control of traffic lights in town. The company ELTODO dopravní systémy Ltd. has some experience with similar traffic control system, especially with system TASS and MOTION inclusive the evaluation of system in area of town. Experiences are reflected verification of algorithm before use in the real traffic on simulator, which will be to include complete regulative loop.

With respect to expansion of new technology and fast processing mathematical algorithm is appropriate to find a new solution accession to optimize control of the traffic network of town. Traffic simulation program AIMSUN with GETRAM Extension interface has been used for programming of traffic light controller model including interfacing mathematical model of control of area programmed in MATLAB. Virtual model of area control has been created in given hierarchical structure which one has all specification of real application for town. It means, that is defined communication by way of interface of intersection controllers with a control algorithm. The control algorithm from traffic data modify appropriate parameters for individual controllers, as are cycle time, duration of stages, offset etc.

It is possible to test programmed virtual module for another mathematical algorithm of the traffic control inclusive modification existing model at the same time. Successive realization for the traffic control with use incoming interface OCIT-I inclusive implementation of modular algorithm to the traffic centre of control will be to service for real application of the traffic control in area of town.

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2^{nd} International Workshop on
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Poster Session

Reconstruction of Attenuation Images in Ultrasound Transmission Tomography

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In breast cancer diagnosis, standard ultrasound B-mode examination provides useful additional diagnostic information. However, interpretation of ultrasound images is very difficult because of poor spatial resolution, low contrast and the presence of speckles. In breast-tissue imaging, ultrasound transmission tomography is an alternative with potentially higher image quality. Although it has been researched for several decades, so far it has not been developed to a clinically applicable state. In this contribution, the current state of our research in attenuation imaging using ultrasound transmission tomography is described.

In our current ultrasound transmission tomography setup, the imaged object, immersed in a water tank, is enclosed by a ring of transducers. One transducer is in the emitter mode, while all other transducers record the received radiofrequency signals. The recording is repeated until all transducers have been used as emitters [1].

The classical approach in ultrasound attenuation tomography has been processing of the directly transmitted focused beam wave, corresponding to the first pulse in the recorded radiofrequency signal. Here, the emitted pulse is unfocused in the tomographic plane. Thus, the recorded signal also includes scattering and reflections from the object in the imaged plane. The main idea is to process also this scattered/reflected signal to utilize more information in the image reconstruction. This is done by means of synthetic aperture focusing to strong scatterers/reflectors. Such signals correspond to non-straight propagation path between the emitter, scatterer/reflector and the receiver.

To estimate the cumulative attenuation along a wave propagation path (straight or non-straight), the method of log-spectral differences is used [2]. It is based on the difference of log-spectra measured with empty water tank and with the object inside.

An overdetermined set of linear equations is constructed with each equation corresponding to one propagation path. The solution of the set is the estimated local-attenuation-coefficient map.

The methods were tested on two data sets: synthetic data and data measured on a phantom.

The results for synthetic data give good qualitative images of attenuation coefficient that are consistent with the attenuation map used for generation of the synthetic data set. For the phantom data, so far only qualitative attenuation maps were achieved.

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Calibration of a Transmission Ultrasound Computed Tomography System

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A method for estimating the frequency- and direction-dependent properties of transducer elements in a transmission ultrasound computed tomography (USCT) [1] system is proposed. Such a system consists of a water tank equipped with numerous unfocused ultrasonic transducer elements arranged on the inner surface of the cylindrical water tank. Each element is used either for emitting or receiving ultrasonic pulse waves that travel through and are scattered in the volume of the tank. USCT systems, still in development, are intended primarily for ultrasonic mammography and seem to be quite promising for this purpose. In order to accurately reconstruct images (using specialized software [2]), the properties of the used transducers must be known. As the transducers age their properties change, and so the system has to be re-calibrated on a regular basis. The presented method calculates a common directivity function and individual sensitivities of all transducer elements (in both, emitting and receiving modes) only by processing an empty measurement – i.e. no external devices or calibration phantoms are needed. The presented approach is a generalization of the 2D method presented in [3] for the case of a 3D system.

The calibration is based on a series of wide-band measurements with the tank filled only with water. Individual received signals (decomposed via DFT into frequency components) can be modeled as a product of the spectrum of the input signal and a set of transfer functions: $S_{out}(f) = S_{in}(f) \cdot R_e(\varphi, f) \cdot T_w(f) \cdot R_r(\varphi, f)$, where S_{in} is the spectrum of the input signal, R_e is the transfer function (radiation pattern) of the emitter element (note that it is both frequency- f and direction- φ dependent), T_w is the transfer function of the water path, and finally R_r is the radiation pattern of the receiver element. The water path transfer function can easily be calculated from: $T_w = e^{-\beta_w f l}$, where β_w denotes the ultrasonic attenuation in water, f is the frequency, and l the distance between the emitting and receiving sensor. The radiation patterns of the emitting and receiving ultrasonic elements are the to-be-calibrated parameters.

If we make a large set of measurements, taking all of the possible combinations of emitter-receiver elements, we are able to construct a set of equations, where the radiation patterns of the individual elements can be solved for. But because the number of unknowns is much larger than the number of equations, some simplifications need to be made. First of all, we can take advantage of the fact that all sensors are of the same kind and were manufactured in the same way. We can therefore assume that all of the transducers will have a common radiation pattern scaled only by a multiplicative parameter "sensitivity" which differs for individual transducer elements due to fatigue and material flaws. Another simplification arises from the fact, that the elements have a symmetrical shape (and therefore a symmetrical radiation pattern), they are positioned in a circular geometry, and each transducer is oriented toward the center of this circle (or cylinder in 3D). By applying these simplifications the initial set of equations changes to: $S_{out} = S_{in}(f) \cdot s_e \cdot s_r \cdot R^2(\varphi_{s \leftrightarrow r}, f) \cdot e^{-\beta_w f l}$, where s_e and s_r are the emitter and receiver sensitivities, and R is the common radiation pattern. By log-linearizing these equations and moving known parameters to the right side we finally arrive at: $log(s_e) + log(s_r) + 2log(R(\varphi_{s \leftrightarrow r}, f)) = log(S_{out}) + log(S_{in}(f)) - \beta_w f l$, which can easily be solved by the least mean squares method in the form $Ax = b$. The model in has thus been extended to include the sensitivities of both the emitters and receivers.

In the future, we are expecting to expand the model to include a 3D common radiation pattern (one dimension for the frequency components and two dimensions for the vertical and horizontal emitting/receiving directions). Also the model will include frequency dependent transfer functions of the electronics carrying the signals to and from the transducers.

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Comparison of Wave-Equation versus Measurement-Processing Transducer Calibration for Ultrasonic Transmission Tomography

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The transmission ultrasonic computed tomography (USCT) is an imaging modality based on simultaneous measurement of responses of many transducers surrounding the imaged object in a circular manner in 2D (or cylindrical in 3D) while one of the transducers is emitting an ultrasonic impulse. Such a system, as experimentally developed in Forschungszentrum Karlsruhe [1] , is primarily aimed at breast imaging.

In the first approximation, all the transducers are equally effective and their directional responses are omni-directional – circular (or spherical, in 3D). Based on this hypothesis, interesting results have been obtained in image reconstruction area [2]. However, these assumptions are obviously not exact, and including more realistic transducer parameters in the image reconstruction promises a substantial improvement in the image quality. In [3], a method to calibrate the individual transducers in terms of their directional characteristics (frequency and direction dependent radiation function) and individual transducer efficiencies has been suggested, based on a simple model of ultrasound transmission and deriving the parameters computationally via solving an extensive system of linear equations. The results provided there seem reasonable, and also a comparison with a hydrophone measurement of a directional characteristic has shown a good qualitative agreement.

However, there is a discrepancy between the computed characteristics and the basic radiation theory: the calculated characteristics contain substantial side-lobes while theoretically only a single main lobe should be present taking into account the small concrete geometrical dimensions of the transducers. In order to try resolve this problem, we applied the wave-equation (WE) based simulation.

This work was intended as the first attempt to an alternative approach to the USCT data analysis. The positive experience with the WE–FEM approach based on the strict physical formulation, although so far limited to the Helmholtz case, is promising with respect to the prospective use of more complex formulation taking into account also the spatially variable attenuation phenomena in the ultrasound field. This should enable a basically different approach to the image reconstruction from the USCT data, based on the iterative inverse problem solution modeling in each step the complete time- and space-dependent ultrasonic field.

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Registration of Frames in Time Series of Autofluorescent Images

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The distribution of lipofuscin (LF) in the retinal pigment epithelium is in correlation with various ophthalmic diseases, thus having a diagnostic value. Detection of LF may be done by auto-fluorescence radiation using confocal scanning laser ophthalmoscope (Heildelberg Retina Angiograph, HRA).

However, the HRA scans are of poor signal/noise ratio (SNR) and can not be used for reliable determination of the LF distribution directly. Improvement of SNR by averaging of frames of HRA scan time series, requires to suppress moving artifacts and perspective distortion via elastic image registration.

With respect to the imaging properties, including the possibility of partial image distortion due to patient movements, the registration requires flexible transforms to be used to align the images; finding the optimum transform parameters via optimization requires using of the similarity criterion based on mutual transform.

The poster describes the used approaches and finally evaluates the results as the correctness and precision of the registration concerns. The precision is evaluated quantitatively via the image sharpness criterion, as the sharpness of the averaged images is substantially influenced by the registration quality. The results are found to be adequate to the final purpose of the pre-processing.

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Properties of the Retinal Nerve Fiber Layer via Color Fundus Images

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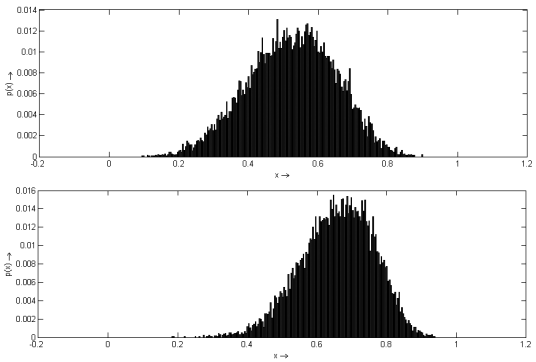
Introduction
The loss of the retinal nerve fiber layer (RNFL) is connected with glaucoma disease, so its quantification can play an important role in its diagnosis. There is an advance imaging technique based on the laser polarimetry for RNFL quantification, but the disadvantage is its cost. Therefore, fundus color imaging technique is used for the RNFL analysis. Although the digital color photography of the retina has been measured for over 15 years [3], there was not paid much attention to RNFL analysis. This work is focused on the selection of the parameters that can be used to distinguish between NFL and non-RNFL. Several statistical and spectral properties are examined here at the beginning of this project.

Preprocessing operations
Green and blue channel were extracted from RAW fundus camera images (Canon D20, [1]) and combined to create gray level image, because spectrum reflection light shows a local maximum on corresponding green-blue wavelength. Local contrast enhancement operation was employed [2] for RNFL enhancement to increase contrast and to eliminate the nonuniform illumination.

Parameters extraction
Several parameters were extracted from the regions that were determined manually from the fundus images. These parameters were extracted for the original image and for the image preprocessed by the local contrast enhancement. Five images were used and 50 RNFL regions and 46 non-RNFL region were manually determined and further analyzed. The size of images was 1761 x 1174 pixels and the size of the region sample was 15 x 15 pixels. Histograms from RNFL and non-RNFL values were constructed and basic statistical parameters evaluated - mean, median, variation coefficient, variance, skewness and entropy. The entropy and variation coefficient seems to be promising parameters for tissue discrimination.



Histograms from several samples within one image: NFL (up) and non-NFL (bottom)

Power spectrum was estimated from RNFL and non-RNFL samples. Periodogram method was used for estimation. These spectra show fine energy differences for RNFL and non-RNFL tissues in diagonal direction and along the line under different angles. This corresponds probably to the orientation of the nerve fibers. Therefore parameters quantifying this energy may be possibly used as a tissue discriminator. The spectral energy in angular sector seems to be another promising discriminator between RNFL and non-RNFL tissue.

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Invariant Recognition Systems in Frequency Domain

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The 2D discrete binary image can be represented as mapping $\mathrm{f}^+ : \{0; \ldots; N-1\}^2 \to \{0, 1\}$. The binary image can be transformed by: translation (T), transformation with orthogonal (O) matrix (rotation, mirroring) and scaling (S). Affine transformation (A) includes also stretching and second rotation beside these transformations. Four methods for invariant features generating were created - two for *TSO* invariant features and two for affine invariant features. The translation invariant *normalized power spectrum* $\Phi_{\mathrm{f}}^+(\overline{\omega})$ $(\max \Phi_{\mathrm{f}}^+(\overline{\omega}) = 1)$ is used in all recognition systems.

TSO Invariant Recognition Systems

Systems are based on *TS* invariant spectrum $\Upsilon_{\mathrm{f}}^+(\overline{\omega}) = \Phi_{\mathrm{f}}^+(\omega^* \overline{\omega})$, where ω^* is referential point, $\omega^* = \min\{\omega \in \mathbb{R}^+, \min_{\|\overline{\omega}\|=\omega} \Phi_{\mathrm{f}}^+(\overline{\omega}) \leq \frac{1}{4}\}$. The first system creates *TSO* invariant *lower and upper relativized envelope* of spectrum Υ^+

$$\mathrm{L}_{\mathrm{f}}^{*+}(\omega) = \min_{\|\overline{\omega}\|=\omega} \Upsilon_{\mathrm{f}}^+(\overline{\omega}), \quad \mathrm{U}_{\mathrm{f}}^{*+} = \max_{\|\overline{\omega}\|=\omega} \Upsilon_{\mathrm{f}}^+(\overline{\omega}). \tag{1}$$

The second system is based on *harmonic analysis of TS invariant spectrum* Υ^+. Here, *TSO* invariants are squared absolute values of Fourier coefficients

$$T_n^+(\omega) = \left| \frac{1}{2\pi} \int_0^{2\pi} \Upsilon^+(\omega \cos\varphi, \omega \sin\varphi) \mathrm{e}^{in\varphi} \, \mathrm{d}\varphi \right|^2. \tag{2}$$

Affine Invariant Recognition Systems

The first step for both recognition systems is construction of *radialized spectrum* $\Psi^+(\overline{\omega}) = \Phi^+(\mathsf{A}^+\overline{\omega})$, where A^+ is special transformation matrix. Then we can create *lower and upper affine invariant envelope*

$$\mathrm{L}_{\mathrm{f}}^{\circ+}(\omega) = \min_{\|\overline{\omega}\|=\omega} \Psi_{\mathrm{f}}^+(\overline{\omega}), \quad \mathrm{U}_{\mathrm{f}}^{\circ+}(\omega) = \max_{\|\overline{\omega}\|=\omega} \Psi_{\mathrm{f}}^+(\overline{\omega}). \tag{3}$$

Otherwise we can use *harmonic analysis of radialized spectrum* Ψ^+, whose result will be affine invariant features – squared absolute values of Fourier coefficients

$$C_n^+(\omega) = \left| \frac{1}{2\pi} \int_0^{2\pi} \Psi^+(\omega \cos\varphi, \omega \sin\varphi) \mathrm{e}^{in\varphi} \, \mathrm{d}\varphi \right|^2. \tag{4}$$

Recognition Systems Testing

Testing of methods was performed on the problem about fish silhouettes recognition. *TSO* and *A* transformed images for ten classes of fish silhouettes were generated. All methods were able to classify binary images to classes according to their shape. When classes of images are disjunct with respect to affine invariance, it is possible to use *A* invariant methods for *TSO* transformed data. These methods give different results, which can be useful in some applications. Generally, better results were obtained by harmonic analysis than by use of invariant envelopes. More information can be found in [1], [2], [3].

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Matlab-Aimsun Interface

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GETRAM is traffic simulator and it consists of two applications. The first one is designer of network and second one is own simulator. There are four basic steps how to use it:

1. Draw the traffic area - basic building objects are lanes, which may be connected into sections, junctions and centroids. The data from detectors are needed for feedback control.
2. Create the control plan - there are three types of junctions: uncontrolled, internal (fixed) controlled from Aimsun and external controlled from other applications. Steps of creating the control plan are: select lines, setup them into signal groups and assign them into phases.
3. Set entrance flows - the main parameters of entrances are: count of vehicles [uv/h], types of cars (car, bus) and turning congistions.
4. Own simulation - new Aimsun scenario made in three or four steps: loading traffic network, loading traffic control, loading result container and alternatively choosing DLL-library, if external control is used.

The Aimsun-Matlab Toolbox is separated into two parts - DLL interface and Matlab functions for easier using. Additional Matlab functions for simulations are:

initArea('AreaName') - initialize and elect current simulation area
getActualData(MyArea) - get intensity, occupancy and velocity
setActualControl(MyArea, MyControl) - set phases lenghts for junctions
demoArea('AreaName') - show area with default control

Results

- *Matlab-Aimsun Interface*
- *Support for easier setup of simulations*
- *Support for easier inclusion of new areas*
- *3 predefined areas (Smichov, Zlicin, Area2)*

Aims

- *Define other areas*
- *Join external model of real controller (Eltodo)*
- *Implement JobControl Interface*

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Modelling of perception of non-planar scene in a defect vision

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The eye is an optical instrument that projects the outer world onto the retina. Even a healthy eye is a relatively imperfect optical system. Our goal is to display how people with a defect of vision see a non-planar scene. It allows us to understand people with eye-defect better. We model an image of a 3D scene captured by the retina (retinal image). The approximation of what the patient sees can be obtained by the convolution measured PSF with a scene. It will work if the scene is planar. We solve the problem of non-planar scene.

First, we estimate the point-spread function (PSF) of the eye. In case of 3D scene, the PSF depends on the depth. The depth is estimated from two images of the scene. We have to make a postprocessing of the rough map. We use the measured PSF for computing of the PSFs in every depth of the scene. After that we apply the space-variant convolution.

Now we describe some parts of the procedure in more detail. Two images of our scene are taken. Both images are focused on the same distance. We choose the values of aperture to achieve two photos with two extremes of depth of field. The size of blur is proportional to the depth of objects but proportionality is different for each image. The convolution mask is estimated by a comparison of the sharp image blurred by the mask and the blurred image. We do this in each point of the image. It serves as a first version of the depth map. We are not able to estimate the depth at homogeneous regions of the image. We have to make a postprocessing of the rough map. We have to define parts of the map where the algorithm could not succeed - constant places. We calculate the 'trustful' function. We use the variance of channels. After that we specify parts of the map as untrustworthy (i. e. parts with large variance) and define these parts using values in their neighbourhood. After that we apply the space-variant convolution.

The rough algorithm works most accurately on edges. The error (between the real depth map and our estimated depth map) is biggest on large constant fields (or almost constant). If we use this inaccurate depth, the error in the convoluted image will be small. The advantage of this approach is that it is not necessary to re-sample the image in comparison with methods using varying distance of focus. More information can be found in [1].

Figure 1: Rough estimation of the depth map (the left image); depth of objects in the scene (the middle image); the final result, estimation of the retinal image (the right image).

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Modeling the Growth of Filamentous Specimens by Means of the Morphological Skeleton

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We introduce a new method for modeling the growth of filamentous specimens in intervals between observations. In phytopathology, the growth parameters of such microorganisms are frequently examined. However, as continuous monitoring of plant pathogenic fungi is very difficult, their development is usually documented repeatedly at a defined time sequence, leaving the growth pattern incomplete. This restriction can be overcome by reconstructing missing images from the images acquired at consecutive observation sessions by means of image warping.

Our method was developed for settled and relatively slow-growing specimens such as fungi and oomycetes with filamentous growth patterns. While their filaments elongate over time, their growth in width and movement are negligible. Hence, we propose to estimate the parameters of the geometrical transform by means of object tracking based on the morphological skeleton [3]. Unlike boundary-based techniques, it does not suffer from deformations of the boundary of curved filaments. For the purpose of warping the images acquired at the beginning and at the end of the missing interval, we recommend elastic geometrical transforms, e.g. radial basis functions called thin-plate splines [1].

The result is a sequence of realistic artificial images that visualize the development of the specimen within the interval between observations. The proposed method does not introduce unnatural deformations and is thus suitable for biomedical data. Its performance was successfully tested on light-microscopy images of *Fusarium oxysporum* [4] germination and mycelium growth (see Fig. 2).

More information on the method can be found in [2].

Figure 2: Preprocessed light-microscopy images of an early (left) and a later (right) stage of the growth of *Fusarium oxysporum* f.sp. *pisi* (*Hyphomycetes*, *Deuteromycotina*). An artificially generated image representing the specimen at 3/5 of the undocumented interval (middle). The image was reconstructed from the available images via warping the temporally closer image (right) by means of thin-plate splines. The parameters of the geometrical transform were computed by means of the presented method.

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Partially Occluded Binary Object Recognition Using Polygonal Approximation

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In this paper we assume partially occluded binary objects deformed by an unknown affine deformation. This assumption approximates real photos with a week perspective deformation. Furthermore, we deal with polygonal shaped objects (i.e. objects with boundary points of a high curvature). The method itself can be divided into two more or less independent parts. The first is a polygonalization of a closed 2D curve; the second is classification of objects represented by their polygonal representation.

Most of the existing methods of polygonal approximation are restricting vertices of the polygon only to the boundary points. In the proposed method, on the other hand, the vertices are computed in real coordinates, and therefore can lie outside (or inside) the boundary, improving precision and stability. Actual algorithm is based on finding longest linear segments of the boundary, beginning from each boundary point, with error of approximation lower than a preset threshold. Afterwards, minimum number of best matching successive approximating lines are chosen and used to form the final polygon. These two steps are in the proposed method combined together, which means, the lines are chosen with respect to the possibility and position of their potential intersections. The final polygon is not invariant to scaling and affine deformation but when we can estimate the amount of scaling, we can partially overcome this problem by using respectively adjusted threshold. The instability of the polygon at smooth nonlinear parts of the object is the reason why this method is designed especially for polygonal shapes.

Having a polygonal representation of an object, we use following method for classification, which takes the partial occlusion into consideration. We compute parameters of affine transforms between all vertices of confronted polygons. At this point, we assume that the corresponding parts of the polygons continue to be similar along the border, and compare only these parameters (not all with each other). Now we find sequences of similar parameters that represent corresponding parts of the polygons and unite those sequences with similar parameters together. That is, the sequences are corresponding to the same affine transform, only to a different part of the border. Finally, we determine the best matching set of sequences. The final result of classification is obtained by comparing the polygon with all model polygons and selecting the best match. As we can see, the proposed classification method is optimized for polygonal shapes with multiple occluded parts of the border and it is invariant to affine transform (can be generalized to nearly any type of transform). Obtained results also show quite good robustness to noise and inaccurate segmentation of the classified objects.

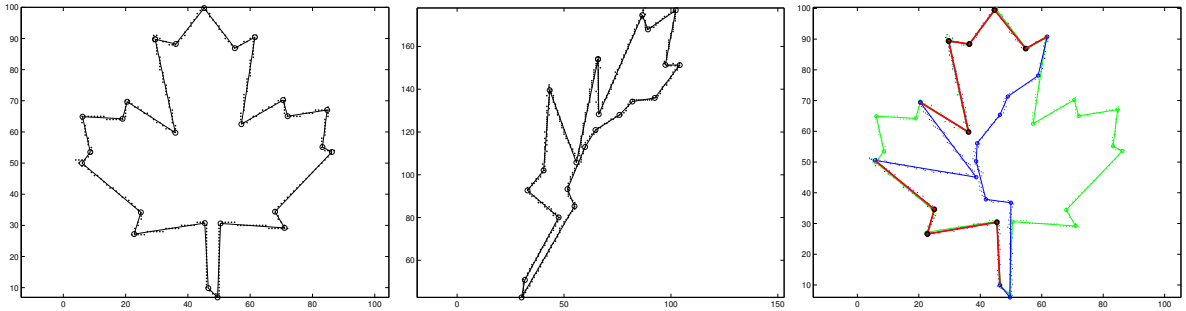

Figure 3: An example of polygonal approximation and its classification

In fig.3 you can see an example of polygonal approximation of a polygonal shape and the result of its classification. More information, experimental images and references on this method can be found in [1].

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Application of image processing in examination of plant-pathogen interactions

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Evaluation of symptoms on a plant is a simple mean of determining the progress of disease. For its speed and unnecessity of special equipment is the visual evaluation still a widely used method. It assesses disease symptoms by various scales and guides. But due to individual subjective evaluation this method does not fulfil requirements on accuracy and reproducibility. These deficits can be partially or fully eliminated by using methods of image processing.

Image processing has a wide application in examination of plant-pathogen interactions, mainly in combination with various laboratory methods like specific colouring of the pathogen body in leaves or colouring of plant's defensive structures and substances and their co-localization with pathogen.

We present several experiments [1, 2], where pathogen body or plant's defensive structures were coloured, the leaves were scanned, and resultant digital image was analyzed by confidence-connected segmentation method [3].

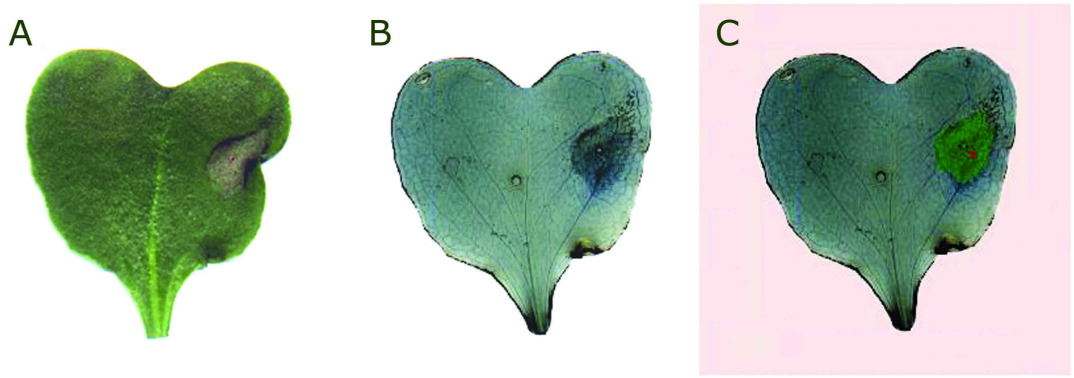

Figure 4: A. Leaf of rape with lesion. B. The same leaf coloured by trypan blue. C. The result of image segmentation: pink colour highlights the background and green colour marks the detected lesion.

References

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The continuous time modelling of controlled traffic network

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The work is dealing with the subtask of the controlled urban traffic optimization. The main task of the work is modelling of the traffic flow in urban traffic network, which is assumed to be controlled by traffic lights and to be observed by traffic detectors.

The model of one lane is the base of the network model. The behaviour at the lane is described using the congested area beginning at traffic lights - inspired by [1]. This area is taken as the artificial object with four characteristics (length, density, outgoing speed and incoming speed). This method can seem oversimplified, but the model is designed for the on-line control and the higher complexity leads to long computing times. The model is also designed for the estimation of the length of congested area (length of queue), which is immeasurable variable characterising the quality of the traffic.

The network model consists of the lane models and the junction models. The junction models connect the lane models by inserting the traffic delay for the real propagation of the intensity and speed through the network. The model variables were chosen to characterise the static and also dynamic parts of the behaviour.

The first experiments with this model are presented at the poster. The main part deals with the graphical presentation of the results - there are shown all modeled variables and the most important of them are compared with the results produced by AIMSUN traffic simulation environment (see [2]) - especially the lengths of congested area.

References

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