Contributed Presentations Abstracts

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CP 1. Polinomial equations I

Talk 1. **Solving multivariate vector polynomial interpolation problems**

The aim of this talk is to present an algorithm for computing a generating set for all multivariate polynomial vectors $(g_1(\mathbf{z}), g_2(\mathbf{z}), \cdots, g_m(\mathbf{z}))^T$ that satisfy the following homogeneous interpolation conditions: $p_{k1}g_1(\boldsymbol{\omega}_k) + p_{k2}g_2(\boldsymbol{\omega}_k) + \cdots + p_{km}g_m(\boldsymbol{\omega}_k) = 0$ for all $1 \leq k \leq l$, where $\boldsymbol{\omega}_k$ are multivariate interpolation points with corresponding interpolation data p_{kj}. Moreover, we are interested in solutions having a specific degree structure. The algorithm will be constructed in such a way that it is easy to extract such solutions. At the same time we also look at different ways of ordering the monomials of multivariate polynomials, in order to obtain more specific information about the degree structure of our solution module. It will turn out that under certain conditions the generating set of the solution module constructed by the algorithm will form a Gröbner basis.

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Talk 2. **A general condition number for polynomial evaluation**

In this talk we present a new expression of the condition number for polynomial evaluation valid for any polynomial basis obtained from a linear recurrence. This expression extends the classical one for the power and Bernstein bases, providing a general framework for all the families of orthogonal polynomials. The use of this condition number permits to give a general theorem about the forward error in the evaluation of finite series in any of these polynomial bases by means of the extended Clenshaw algorithm. A running-error bound is also presented and all the bounds are compared in several numerical examples.

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Talk 3. **The geometry of multivariate polynomial division and elimination**

Multivariate polynomials are usually discussed in the framework of algebraic geometry. Solving problems in algebraic geometry usually involves the use of a Gröbner basis. This talk will show that linear algebra without any Gröbner basis computation suffices to solve basic problems from algebraic geometry by describing three operations: multiplication, division and elimination. This linear algebra framework will also allow us to give a geometric interpretation. Division will involve oblique projections and a link between elimination and principal angles between subspaces (CS decomposition) will be revealed. The main computations in this framework are the QR and Singular Value Decomposition of sparse structured matrices.

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Talk 4. **Characterization and construction of classical orthogonal polynomials using a matrix approach**

We identify a polynomial sequence $u_n(x) = a_{n,0} + a_{n,1}x + \cdots + a_{n,n}x^n$ with the infinite lower triangular matrix $[a_{n,k}]$. Using such matrices we obtain basic properties of orthogonal sequences such as the representation as characteristic polynomials of tri-diagonal matrices and the 3-term recurrence relation $u_{n+1}(x) = (x - \beta_n)u_n(x) - \alpha_n u_{n-1}(x)$. Then we characterize the classical orthogonal sequences as those that satisfy the equation $(5v + w)\alpha_2 = (v + 2w)(v^2 + \alpha_1)$, where $v = \beta_1 - \beta_0$, $w = \beta_2 - \beta_1$, $\alpha_1 > 0$, $\alpha_2 > 0$, and also give certain pair of diagonals equal to zero in a matrix constructed from $[a_{n,k}]$. For each choice of the parameters v, w, α_1, we find explicit expressions for all the α_k, β_k. In the case $v = w = 0$ we obtain a one-parameter family of classical orthogonal sequences that includes the Chebyshev, Legendre, and Hermite sequences and also contains the sequence of derivatives of each of its elements.
Our matrix methods can be used to study other classes of orthogonal sequences.

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CP 2. Structured matrices I

Talk 1. **Determinants and inverses of circulant matrices with Jacobsthal and Jacobsthal-Lucas numbers**

Let $\mathbb{J}_n := \mathrm{circ}(J_1, J_2, \ldots, J_n)$ and $\daleth_n := \mathrm{circ}(j_0, j_1, \ldots, j_{n-1})$ be the $n \times n$ circulant matrices ($n \geq 3$) whose elements are Jacobsthal and Jacobsthal-Lucas numbers, respectively. The determinants of $\mathbb{J}_n$ and $\daleth_n$ are obtained in terms of J_n and j_n, respectively. These imply that $\mathbb{J}_n$ and $\daleth_n$ are invertible. We also derive the inverses of $\mathbb{J}_n$ and $\daleth_n$.

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Talk 2. **Determinants and inverses of circulant matrices with**

Pell and Pell-Lucas numbers

In this talk, we define two n-square circulant matrices whose elements are Pell and Pell-Lucas numbers in the following form

$$\mathcal{P}_n = \begin{pmatrix} P_1 & P_2 & \cdots & P_{n-1} & P_n \\ P_n & P_1 & \cdots & P_{n-2} & P_{n-1} \\ P_{n-1} & P_n & \cdots & P_{n-3} & P_{n-2} \\ \vdots & \vdots & & \vdots & \vdots \\ P_2 & P_3 & \cdots & P_n & P_1 \end{pmatrix}$$

and

$$\mathfrak{P}_n = \begin{pmatrix} Q_1 & Q_2 & \cdots & Q_{n-1} & Q_n \\ Q_n & Q_1 & \cdots & Q_{n-2} & Q_{n-1} \\ Q_{n-1} & Q_n & \cdots & Q_{n-3} & Q_{n-2} \\ \vdots & \vdots & & \vdots & \vdots \\ Q_2 & Q_3 & \cdots & Q_n & Q_1 \end{pmatrix}$$

where P_n is the nth Pell number and Q_n is the nth Pell-Lucas number. Then we compute determinants of the matrices. We also obtain formulas which give elements of inverse of the matrices.

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Talk 3. **Eigenproblem for circulant and Hankel matrices in extremal algebra**

Eigenvectors of circulant and Hankel matrices in fuzzy (max-min) algebra are studied. Both types of matrices are determined by vector of inputs in the first row. Investigation of eigenvectors in max-min algebra is important for applications connected with reliability of complex systems, with fuzzy relations and further questions. Many real systems can be represented by matrices of special form. Description of the eigenproblem for the above special types of matrices is important because for special types of matrices the computation can often be performed in a simpler way than in the general case.

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Talk 4. **Inverses of generalized Hessenberg matrices**

Some constructive methods are proposed for the inversion of a generalized (upper) Hessenberg matrix (with subdiagonal rank ≤ 1) $A \in GL(n, K)$, see e.g. *L. Elsner, Linear Algebra Appl. 409 (2005) pp. 147-152*, where a general structure theorem for such matrices was provided. They are based in its related Hessenberg-like matrix B=A(2:n,1:n-1). If B is also a generator representable matrix, i.e. $a_{n,1} \neq 0$, the form $A^{-1} = U^{-1} + YX^T$ is easily obtained using the Sherman-Morrison-Woodbury formula. When B is strictly nonsingular, an inverse factorization $A^{-1} = H_L H_U$, based on Hessenberg matrices, is provided. Concerns about the remaining general situation are also outlined.

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CP 3. Matrix factorization

Talk 1. **Modified symplectic Gram-Schmidt process is mathematically and numerically equivalent to Householder SR algorithm**

In this talk, we present two new and important results. The first is that the SR factorization of a matrix A via the modified symplectic Gram-Schmidt (MSGS) algorithm is mathematically equivalent to Householder SR algorithm applied to an embedded matrix obtained from A by adding two blocks of zeros in the top of the first half and in the top of the second half of the matrix A. The second result is that MSGS is also numerically equivalent to Householder SR algorithm applied the mentioned embedded matrix. The later algorithm is a Householder QR-like algorithm, based on some specified elementary symplectic transformations which are rank-one modification of the identity. Numerical experiments will be given.

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Talk 2. **A multi-window approach to deflation in the QR algorithm**

Aggressive Early Deflation significantly improved the performance of Francis' QR algorithm by identifying deflations in matrices 'close to' the Hessenberg iterate (see The Multishift QR Algorithm. Part II. Aggressive Early Deflation. Braman, Byers and Mathias. SIAM J. Matrix Anal. Appl., 23(4):948-973, 2002). The perturbations used in AED focused on a 'deflation window' which was a trailing principal submatrix. Recently, this idea has been extended to investigate the effect of allowing simultaneous perturbations in more than one location. In this talk we present new results on this 'multi-window' approach and its effect on the performance of the QR algorithm.

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Talk 3. **Aggregation of the compact WY representations generated by the TSQR algorithm**

The TSQR (Tall-and-Skinny QR) algorithm is a parallel algorithm for the Householder QR decomposition proposed recently by Langou. Due to its large-grain parallelism, it can achieve high efficiency in both shared-memory and distributed-memory parallel environments. In this talk, we consider the situation where we first compute the QR decomposition of $A \in \mathbf{R}^{m\times n}$ $(m \gg n)$ by the TSQR algorithm and then compute $Q^T B$ for another matrix $B \in \mathbf{R}^{m\times l}$. We further assume that the first step is performed on a multicore processor with p cores, while the latter step is performed by an accelerator such as the GPU. In that case, the original TSQR algorithm may not be optimal, since the Q factor generated by the TSQR algorithm consists of many small Householder transformations or compact WY representations of length m/p

and $2n$, and as a result, the vector length in the computation of $Q^T B$ is shortened. To solve the problem, we propose a technique to aggregate the compact WY representations generated by the TSQR algorithm into one large compact-WY like representation. In this way, both the large-grain parallelism of the TSQR algorithm and the long vector length in the computation of $Q^T B$ can be exploited. We show the effectiveness of our technique in a hybrid multicore-GPU environment.

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Talk 4. **A generalized SVD for collections of matrices**
The generalized SVD for a pair of matrices is a simultaneous diagonalization. Given matrices D_1 $(m_1 \times n)$ and D_2 $(m_2 \times n)$, it is possible to find orthogonal matrices U_1 and U_2 and a nonsingular X so that $U_1^T D_1 X = \Sigma_1$ and $U_2^T D_2 X = \Sigma_2$ are both diagonal. In our generalization, we are given matrices, $D_1, \ldots, D_N$ each of which has full column rank equal to n. By working implicitly (and carefully) with the eigensystem of the matrix $\sum_{ij} (D_i^T D_i)(D_j^T D_j)^{-1}$ we are able to simultaneously "take apart" the D_i and discover common features. The new reduction reverts to the GSVD if $N = 2$.

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CP 4. Krylov methods

Talk 1. **Fixed-point Lanczos with analytical variable bounds**
We consider the problem of establishing analytical bounds on all variables calculated during the symmetric Lanczos process with the objective of enabling fixed-point implementations with no overflow. Current techniques fail to provide practical bounds for nonlinear recursive algorithms. We employ a diagonal preconditioner to control the range of all variables, regardless of the condition number of the original matrix. Linear algebra techniques are used to prove the proposed bounds. It is shown that the resulting fixed-point implementations can lead to similar numerical behaviour as with double precision floating-point while providing very significant performance improvements in custom hardware implementations.

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Talk 2. **An Arnoldi-based method for model order reduction of delay system**
For large scale time-delay systems, Michiels, Jarlebring, and Meerbergen gave an efficient Arnoldi-based model order reduction method. To reduce the order from n to k, their method needs $nk^2/2$ memory. In this talk, we propose a new implementation for the Arnoldi process, which is numerical stable and needs only nk memory.

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Talk 3. **The Laurent-Arnoldi process, Laurent interpolation, and an application to the approximation of matrix functions**
The Laurent-Arnoldi process is an analog of the standard Arnoldi process applied to the extended Krylov subspace. It produces an orthogonal basis for the subspace along with a generalized Hessenberg matrix whose entries consist of the recursion coefficients. As in the standard case, the application of the process to certain types of linear operators results in recursion formulas with few terms. One instance of this occurs when the operator is isometric. In this case, the recursion matrix is the pentadiagonal CMV matrix and the Laurent-Arnoldi process essentially reduces to the isometric Arnoldi process in which the underlying measures differ only by a rotation in the complex plane. The other instance occurs when the operator is Hermitian. This case produces an analog of the Lanczos process where, analogous to the CMV matrix, the recursion matrix is pentadiagonal. The Laurent polynomials generated by the recursion coefficients have properties similar to those of the Lanczos polynomials. We discuss the interpolating properties of these polynomials in order to determine remainder terms for rational Gauss and Radau rules. We then apply our results to the approximation of matrix functions and functionals.

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Talk 4. **On worst-case GMRES**
Let a nonsingular matrix A be given. By maximizing the GMRES residual norm at step k over all right hand sides from the unit sphere we get an approximation problem called the *worst-case GMRES problem*. In this contribution we concentrate on characterization of this problem. In particular, we will show that worst-case starting vectors satisfy the so called cross-equality and that they are always right singular vectors of the matrix $p_k(A)$ where p_k is the corresponding worst-case GMRES polynomial. While the ideal GMRES polynomial is always unique, we will show that a worst-case GMRES

polynomial needs not be unique.

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CP 5. Control systems I

Talk 1. **Structured perturbation of a controllable pair**
We study the variation of the controllability indices of a pair $(A, B) = (A, [B_1 \ \ b]) \in \mathbb{C}^{n\times n} \times \mathbb{C}^{n\times(m_1+1)}$, where (A, B_1) is controllable, when we make small additive perturbations on the last column of B. Namely, we look for necessary conditions that must be satisfied by the controllability indices of $(A, [B_1 \ \ b'])$ where b' is sufficiently close to b.
On the other hand, if ε is a sufficiently small real number, we look for (necessary and sufficient) conditions that must be satisfied by a partition in order to be the partition of the controllability indices (or, equivalently, those of Brunovsky) of $(A, [B_1 \ \ b'])$ for some b' such that $\|b' - b\| < \varepsilon$. These problems can be considered as perturbation problems as well as completion problems, since one part of the matrix remains fixed. Because of this, we talk about structured perturbation.

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Talk 2. **Reduction to miniversal deformations of families of bilinear systems**
Bilinear systems under similarity equivalence are considered. Using Arnold technique a versal deformation of a differentiable family of bilinear systems is derived from the tangent space and orthogonal bases for a normal space to the orbits of similar equivalent bilinear systems. Versal deformations provide a special parametrization of bilinear systems space, which can be applied to perturbation analysis and investigation of complicated objects like singularities and bifurcations in multi-parameter bilinear systems.

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Talk 3. **Matrix stratifications in control applications**
In this talk, we illustrate how the software tool StratiGraph can be used to compute and visualize the closure hierarchy graphs associated with different orbit and bundle stratifications. The stratification provides the user with qualitative information of a dynamical system like how the dynamics of the control problem and its system characteristics behave under perturbations.
We investigate linearized models of mechanical systems which can be represented by a linear time-invariant (LTI) system. We also analyze dynamical systems described by linear time-invariant differential-algebraic sets of equations (DAEs), which often are expressed as descriptor models.

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Talk 4. **Stratification of structured pencils and related topics**
In this talk we present new results on stratifications (i.e., constructing closure hierarchies) of structured pencil orbits under congruence transformations: $O(A, B) = \{S^T(A, B)S$ s.t. $\det S \neq 0,$ and A, B are symmetric or skew symmetric matrices$\}$. We use the canonical forms given by Thompson [Linear Algebra Appl. 147(1991), 323–371] as the representatives of the orbits. In particular, miniversal deformations are derived and codimensions of the orbits are computed by solving associated systems of matrix equations (codimensions can also be calculated from the miniversal deformations). One goal is to reduce the stratifications of structured pencils under congruence transformations to the well studied and solved problems for stratifications of matrix pencils.

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CP 6. Preconditioning I

Talk 1. **Memory optimization to build a Schur complement**
One promising algorithm for solving linear system is the hybrid method based on domain decomposition and Schur complement (used by HIPS and MAPHYS for instance).
In this method, a direct solver is used as a subroutine on each subdomain matrix; unfortunately, these calls are subject to serious memory overhead. With our improvements, the direct solver PASTIX can easily scale in terms of performances with several nodes composed of multicore chips and forthcoming GPU accelerators, and the memory peak due to Schur complement computation can be reduce by 10% to 30%.

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Talk 2. **On generalized inverses in solving two-by-two block linear systems**
The goal is to analyze a role of generalized inverses in the projected Schur complement based algorithm for solving nonsymmetric two-by-two block linear systems. The outer level of the algorithm combines the Schur complement reduction with the null-space method in order to treat the singularity of the (1,1)-block. The inner level uses a projected variant of the Krylov subspace method. We prove that the inner level is invariant to the choice of a generalized inverse to the (1,1)-block so that each generalized inverse is internally adapted to the More-Penrose one. The algorithm extends ideas used in the background of the FETI domain decomposition methods. Numerical experiments confirm the theoretical results.

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Talk 3. **Sparse direct solver on top of large-scale multicore systems with GPU accelerators**
In numerical simulations, solving large sparse linear systems is a crucial and time-consuming step. Many parallel factorization techniques have been studied. In PaStiX solver, we developed a dynamic scheduling for strongly hierarchical modern architectures. Recently, we evaluated how to replace this scheduler by generic frameworks (DAGuE or StarPU) to execute the factorization tasks graph. Since sparse direct solvers are built with dense linear algebra kernels, we are implementing prototype versions of solvers on top of PLASMA and MAGMA libraries. We aim at designing algorithms and parallel programming models to implement direct methods on GPU-equipped computers.

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Talk 4. **New block distributed Schur complement preconditioners for CFD simulation on many-core architectures**
At the German Aerospace Center, the parallel simulation systems TAU and TRACE have been developed for the aerodynamic design of aircrafts or turbines for jet engines. For the parallel iterative solution of large, sparse real or complex systems of linear equations, required for both CFD solvers, block-local preconditioners are compared with reformulated global block Distributed Schur Complement (DSC) preconditioning methods. Numerical, performance and scalability results of block DSC preconditioned FGMRes algorithms are presented for typical TAU and TRACE problems on many-core systems together with an analysis of the avantages of using block compressed sparse matrix data formats.

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CP 7. Least squares

Talk 1. **Partially linear modeling combining least squares support vector machines and sparse linear regression**
In this talk we propose an algorithm to efficiently solve a partially linear optimization problem in which the linear relation will be sparse and the non-linear relation will be non-sparse. The sparsity in the linear relation will be obtained by punishing the complexity of the corresponding weight vector similarly as in LASSO or group LASSO. The non-linear relation is kernel-based and its complexity is punished similarly as in Least Squares Support Vector Machines (LS-SVM). To solve the optimization problem we eliminate the non-linear relation using a Singular Value Decomposition. The remaining optimization problem can be solved using existing solvers.

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Talk 2. **Construction of test instances with prescribed properties for sparsity problems**
For benchmarking algorithms solving

$$\min \|x\|_1 \text{ subject to } Ax = b,$$

it is desirable to create test instances containing a matrix A, a right side b and a known solution $\tilde{x}$. To guarantee the existence of a solution with prescribed sign pattern, the existence of a dual certificate w satisfying $A^T w \in \partial\|\tilde{x}\|_1$ is necessary and sufficient. As used in the software package L1TestPack, alternating projections calculate a dual certificate with least squares on the complement of the support of $\tilde{x}$. In this talk, we present strategies to construct test instances with different additional properties such as a maximal support size or favorable dual certificate.

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Talk 3. **Weighted total least-squares collocation with geodetic applications**
The Total Least-Squares (TLS) approach to Errors-In-Variables Models is well established, even in the case of correlation among the observations, and among the elements of the coefficient matrix, as long as the two are not cross-correlated. Adding

stochastic prior information transforms the fixed parameter vector into a random effects vector to be predicted rather than estimated. Recently, Schaffrin found a TLS solution for this case, if the data were assumed iid. Here, this assumption is dropped, leading to a technique that is perhaps best called Weighted Total-Least Squares Collocation. A fairly general algorithm will be presented along with an application.

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Talk 4. **Polynomial regression in the Bernstein basis**
One important problem in statistics consists of determining the relationship between a response variable and a single predictor variable through a regression function. In this talk we consider the problem of linear regression when the regression function is an algebraic polynomial of degree less than or equal to n. The coefficient matrix A of the overdetermined linear system to be solved in the least squares sense usually is an ill-conditioned matrix, which leads to a loss of accuracy in the solution of the corresponding normal equations.
If the monomial basis is used for the space of polynomials A is a rectangular Vandermonde matrix, while if the Bernstein basis is used then A is a rectangular Bernstein-Vandermonde matrix. Under certain conditions both classes of matrices are totally positive, and this can advantageously be used in the construction of algorithms based on the QR decomposition of A.
In the talk, the advantage of using the Bernstein basis is to be shown.

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CP 8. Miscellaneous I

Talk 1. **Reduced basis modeling for parametrized systems of Maxwell's equations**
The Reduced Basis Method generates low-order models to parametrized PDEs to allow for efficient evaluation of parametrized models in many-query and real-time contexts.
We apply the Reduced Basis Method to systems of Maxwell's equations arising from electrical circuits. Using microstrip models, the input-output behaviour of interconnect structures is approximated with low order reduced basis models for a parametrized geometry, like distance between microstrips and/or material coefficients, like permittivity and permeability of substrates.
We show the theoretical framework in which the Reduced Basis Method is applied to Maxwell's equations and present first numerical results.

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Talk 2. **A new alternative to the tensor product in wavelet construction**
Tensor product has been a predominant method in constructing multivariate biorthogonal wavelet systems. An important feature of tensor product is to transform univariate refinement filters to multivariate ones so that biorthogonality of the univariate refinement filters is preserved. In this talk, we introduce an alternative transformation, to which we refer as Coset Sum, of tensor product. In addition to preserving biorthogonality of univariate refinement filters, Coset Sum shares many other essential features of tensor product that make it attractive in practice. Furthermore, Coset Sum can even provide wavelet systems whose algorithms are faster than the ones based on tensor product.

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Talk 3. **Purely algebraic domain decomposition methods for incompressible Navier-Stokes equation**
In the context of domain decomposition methods, an algebraic approximation of the transmission condition (TC) is proposed in "F. X. Roux, F. Magoules, L. Series. Y. Boubendir, Algebraic approximations of Dirichlet-to-Neumann maps for the equations of linear elasticity, Comput. Methods Appl. Mech. Engrg., 195, 3742-3759, 2006". For the case of non overlapping domains, approximations of the TCs are analogous to the approximation of the Schur complements (SC) in the incomplete block factorization. The basic idea is to approximate the SC by a small SC approximations in patches. The computation of these local transmissions are constructed independently, thus enhancing the parallelism in the overall approximation.
In this work, a new computation of local Schur complement is proposed and the method is tested on steady state incompressible Navier-Stokes problems discretized using finite element method. The earlier attempts used in the literature approximate the TC by building small patches around each node. The method is generalized by aggregating the nodes and thus reducing the overlapping computation of local TCs. Moreover, the approach of aggregating the nodes is based on the "numbering" of the nodes rather than on the "edge connectivity" between the nodes as previously done in the reference above.
With the new aggregation scheme, the construction time is significantly less. Furthermore, the new aggregation based approximation leads to a completely parallel solve phase. The new method is tested on the difficult cavity problem with high reynolds number on uniform and streatched grid. The parallelism of the new method is also discussed.

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Talk 4. **On specific stability bounds for linear multiresolution schemes based on biorthogonal wavelets**
Some Biorthogonal bases of compactly supported wavelets can

be considered as a cell-average prediction scheme within Harten's framework. In this paper we express the Biorthogonal prediction operator as a combination of some finite differences. Through a detailed analysis of certain contractivity properties, we arrive at specific stability bounds for the multiresolution transform. A variety of tests indicate that these bounds are close to numerical estimates.

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CP 9. Eigenvalue problems I

Talk 1. **Incremental methods for computing extreme singular subspaces**

The oft-described family of low-rank incremental SVD methods approximate the truncated singular value decomposition of a matrix A via a single, efficient pass through the matrix. These methods can be adapted to compute the singular triplets associated with either the largest or smallest singular values. Recent work identifies a relationship with an optimizing eigensolver over $A^T A$ and presents multi-pass iterations which are provably convergent to the targeted singular triplets. We will discuss these results, and provide additional analysis, including circumstances under which the singular triplets are exactly computed via a single pass through the matrix.

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Talk 2. **An efficient implementation of the shifted subspace iteration method for sparse generalized eigenproblems**

We revisit the subspace iteration (SI) method for symmetric generalized eigenvalue problems in the context of improving an existing solver in a commercial structural analysis package. A new subspace algorithm is developed that increases the efficiency of the naïve SI by means of novel shifting techniques and locking. Reliability of results is ensured using stronger convergence criterion and various control parameters are exposed to the end user. The algorithm is implemented in software using the C++ library 'Eigen'. Results are presented and we end with an introduction to a new, communication reducing method for sparse matrix-vector multiplication that we envisage will increase efficiency further.

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Talk 3. **Recursive approximation of the dominant eigenspace of an indefinite matrix**

We consider here the problem of tracking the dominant eigenspace of an indefinite matrix by updating and downsizing recursively a low rank approximation of the given matrix. The tracking uses a window of the given matrix, which is is adapted at every step of the algorithm. This increases the rank of the approximation, and hence requires a rank reduction of the approximation. In order to perform the window adaptation and the rank reduction in an efficient manner, we make use of a new anti-triangular decomposition for indefinite matrices. All steps of the algorithm only make use of orthogonal transformations, which guarantees the stability of the intermediate steps.

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Talk 4. **Jacobi-Davidson type methods using a shift invariance property of Krylov subspaces for eigenvalue problems**

The Jacobi-Davidson method is a subspace method for a few eigenpairs of a large sparse matrix. In the method, one has to solve a nonlinear equation, the so-called correction equation, to generate subspaces. The correction equation is approximately solved after a linearization that corresponds to replacing a desired eigenvalue with its approximation. In this talk, we focus on the nonlinear correction equation. Here, a Krylov subspace is generated, not only to compute approximate eigenvalues which lead to a class of linearized correction equations, but also to solve the linearized correction equations. Our approach reproduces the Jacobi-Davidson method and the Riccati method, and derives new efficient variants.

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CP 10. Miscellaneous II

Talk 1. **Phylogenetic trees via latent semantic indexing**

In this talk we discuss a technique for constructing phylogenetic trees from a set of whole genome sequences. The method does not use local sequence alignments but is instead based on latent semantic indexing, which involves a reduction of dimension via the singular value decomposition of a very large polypeptide-by-genome frequency matrix. Distance measures between species are then obtained. These are used to generate a phylogenetic tree relating the species under consideration.

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Talk 2. **Synchronization of rotations via Riemannian trust-regions**

We estimate unknown rotation matrices $R_i \in \mathrm{SO}(n = 2, 3)$ from a set of measurements of relative rotations $R_i R_j^T$. Each measurement is either slightly noisy, or an outlier bearing no information. We study the case where most measurements are outliers. In (A. Singer, *Angular Synchronization by Eigenvectors and Semidefinite Programming*, ACHA 30(1), pp. 20–36, 2011), an estimator is computed from a dominant subspace of a matrix. We observe this essentially results in least-squares estimation, and propose instead a Maximum Likelihood Estimator, explicitly acknowledging outliers. We compute the MLE via trust-region optimization on a matrix manifold. Comparison of our estimator with Riemannian Cramér-Rao bounds suggests efficiency.

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CP 11. Miscellaneous III

Talk 1. **A new multi-way array decomposition**

This talk draws a new perspective on multilinear algebra and the multi-way array decomposition. A novel decomposition technique based on Enhanced Multivariance Product Representation (EMPR) is introduced. EMPR is a derivative of High Dimensional Model Representation (HDMR), which is a divide-and-conquer algorithm. The proposed technique provides a decomposition by rewriting multi-way arrays in a form that consists of outer products of certain support vectors. Each support vector corresponds to a different subspace of the original multi-way array. Such an approach can improve the semantic meaning of the decomposition by eliminating rank considerations. Compression of animations is performed as an initial experimental evaluation.

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Talk 2. **Towards more reliable performances of accurate floating-point summation algorithms**

Several accurate algorithms to sum IEEE-754 floating point numbers have been recently published, *e.g.* Rump-Ogita-Oishi (2008, 2009), Zhu-Hayes (2009, 2010). Since some of these actually compute the correct rounding of the exact sum, run-time and memory performances become the discriminant property to decide which one to choose. In this talk we focus the difficult problem of presenting reliable measures of the run-time performances of such core algorithms. We present an almost machine independent analysis based on the instruction-level parallelism of the algorithm. Our PerPI software tool automatizes this analysis and provides a more reliable performance analysis.

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CP 12. Matrix norms

Talk 1. **Numerical solutions of singular linear matrix differential equations**

The main objective of this talk is to provide a procedure for discretizing an initial value problem of a class of linear matrix differetial equations whose coefficients are square constant matrices and the matrix coefficient of the highest-order derivative is degenerate. By using matrix pencil theory, first we give necessary and sufficient conditions to obtain a unique solution for the continuous time model. After by assuming that the input vector changes only at equally space sampling instants we shall derive the corresponding discrete time state equation which yield the values of the solutions of the continuous time model.

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Talk 2. **Matrix version of Bohr's inequality**

The classical Bohr's inequality states that for any $z, w \in \mathbb{C}$ and for $p, q > 1$ with $\dfrac{1}{p} + \dfrac{1}{q} = 1$,

$$|z + w|^2 \le p|z|^2 + q|w|^2$$

with equality if and only if $w = (p-1)z$. Several operator generalizations of the Bohr inequality have been obtained by some authors. Vasić and Kečkić, (Math. Balkanica, 1(1971) 282-286), gave an interesting generalization of the inequality of the following form

$$\left|\sum_{j=1}^{m} z_j\right|^r \le \left(\sum_{j=1}^{m} p_j^{\frac{1}{1-r}}\right)^{r-1} \sum_{j=1}^{m} p_j |z_j|^r,$$

where $z_j \in \mathbb{C},\ p_j > 0,\ r > 1.$

In this talk we aim to give weak majorization inequalities for matrices and apply it to prove eigenvalue extension of the result by Vasić and Kečkić and unitarily norm extensions.

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CP 13. Code theory

Talk 1. **Linear codes in LRTJ spaces**

In [S. Jain, *Array Codes in the Generalized-Lee-RT-Pseudo-Metric (the GLRTP-Metric)*, to appear in Algebra Colloquium.], Jain introduced a new metric viz. LRTJ-metric on the space $Mat_{m\times s}(\mathbf{Z}_q)$, the module space of all $m \times s$ matrices with entries from the finite ring $\mathbf{Z}_q (q \ge 2)$ generalizing the classical one dimensional Lee metric [C. Y. Lee, *Some properties of non-binary error correcting codes*, IEEE

Trans. Information Theory, IT-4 (1958), 77-82] and the two-dimensional RT-metric [M.Yu. Rosenbloom and M.A. Tsfasman, *Codes for m-metric*, Problems of Information Transmission, 33 (1997), 45-52] which further appeared in [E. Deza and M.M. Deza, Encyclopedia of Distances, Elsevier, 2008, p.270]. In this talk, we discuss error control techniques viz. error detection and error correction in linear codes equipped with LRTJ-metric in communication channels[S. Jain, *Array Codes in the Generalized-Lee-RT-Pseudo-Metric (the GLRTP-Metric)*, to appear in Algebra Colloquium]. We further discuss various properties of the dual code of an LRTJ code and obtain the relation for the complete weight enumerator of the dual code of an array code in LRTJ spaces in the form of MacWilliams duality relations[S. Jain, *MacWilliams Duality in LRTJ-Spaces*, to appear in Ars Combinatoria].

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Talk 2. **On turbo codes of rate $1/n$ from linear systems point of view**

Turbo codes were introduced by Berrou, Glavieux and Thitimajshima in 1993. Their idea of using parallel concatenation of recursive systematic convolutional codes with an interleaver was a major step in terms of achieving low bit error rates at signal to noise ratios near the Shannon limit. One of the most important parameter of turbo codes is the effective free distance, introduced by Berrou and Montorsi. It plays a role similar to that of the free distance for convolutional codes. Campillo, Devesa, Herranz and Perea developed turbo codes in the framework of the input-state-output representation for convolutional codes. In this talk, using this representation, we present conditions for a turbo code with rate $1/n$ in order to achieve maximum effective free distance.

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CP 14. Iterative methods I

Talk 1. **Meshless method for steady Burgers' equation: a matrix equation approach**

In this talk we present some numerical linear algebra methods to solve a Burgers equations. A meshless method based on thin plate splines is applied to a non homogeneous steady Burgers' equation with Dirichlet boundary condition. The numerical approximation of the solution leads to a large-scale nonlinear matrix equation. In order to implement the inexact Newton algorithm to solve this equation, we focus ourselves on the jacobian matrix related to this method and establish some interesting matrix relations. The obtained linear matrix equation will be solved using a global GMRES method. Numerical examples will be given to illustrate our method.

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Talk 2. **Tuned preconditioners for inexact two-sided inverse and Rayleigh quotient iteration**

We consider two-sided inner-outer iterative methods based on inverse and Rayleigh quotient iteration for the numerical solution of non-normal eigenvalue problems. There, in each outer iterations two adjoint linear systems have to be solved, but it is often sufficient to solve these systems inexactly and still preserve the fast convergence of the original exact algorithm. This can, e.g., be accomplished by applying a limited number of steps of a Krylov subspace method for linear systems. To reduce the number of these inner iterations, preconditioners are usually applied. In the one-sided case it is even possible to keep the number of inner iterations almost constant during the course of the inner-outer method by applying so called tuned preconditioners. We investigate how these ideas can be carried over to the two-sided case. A special interest there is the simultaneous solution of the occurring adjoint linear systems using methods based on the two-sided Lanczos process, e.g., BiCG and QMR.

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CP 15. Polynomial equations II

Talk 1. **Standard triples of structured matrix polynomials**

The notion of standard triples plays a central role in the theory of matrix polynomials. We study such triples for matrix polynomials $P(\lambda)$ with structure $\mathcal{S}$, where $\mathcal{S}$ is the Hermitian, symmetric, adj-even, adj-odd, adj-palindromic or adj-antipalindromic structure (with $\mathrm{adj} = *, T$). We introduce the notion of $\mathcal{S}$-structured standard triple. With the exception of T-(anti)palindromic matrix polynomials of even degree with both -1 and 1 as eigenvalues, we show that $P(\lambda)$ has structure $\mathcal{S}$ if and only if $P(\lambda)$ admits an $\mathcal{S}$-structured standard triple, and moreover that every standard triple of a matrix polynomial with structure $\mathcal{S}$ is $\mathcal{S}$-structured. We investigate the important special case of $\mathcal{S}$-structured Jordan triples.

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Talk 2. **Solving systems of polynomial equations using (numerical) linear algebra**

Solving multivariate polynomial equations is central in optimization theory, systems and control theory, statistics, and several other sciences. The task is phrased as a (numerical) linear algebra problem involving a large sparse matrix containing the coefficients of the polynomials. Two approaches to retrieve all solutions are discussed: In the nullspace-based algorithm an eigenvalue problem is obtained by applying realization theory to the nullspace of the coefficient matrix. Secondly in the data-driven approach one operates directly on the coefficient matrix and solves linear equations using the QR-decomposition yielding an eigenvalue problem in the triangular factor R. Ideas are developed on the levels of geometry (e.g., column/row spaces, orthogonality), numerical linear algebra (e.g., Gram-Schmidt orthogonalization, ranks) and algorithms (e.g., sparse nullspace computations, power method).

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CP 16. Matrices and algebraic structures

Talk 1. **Determinantal range and Frobenius endomorphisms**

For $A, C \in M_n$ the set
$W_C(A) = \{Tr\,(AUCU^*) : UU^* = I_n\}$ is the C-*numerical range* of A and it reduces to the classical numerical range, when C is a rank one Hermitian orthogonal projection. A variation of $W_C(A)$ is the C-determinantal range of A, that is, $\triangle_C(A) = \{\det(A - UCU^*) : UU^* = I_n\}$. We present some properties of this set and characterize the additive Frobenius endomorphisms for the determinantal range on the whole matrix algebra M_n and on the set of Hermitian matrices H_n.

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Talk 2. **On algorithms for constructing $(0, 1)$-matrices with prescribed row and column sum vectors**

Given partitions R and S with the same weight and $S \preceq R^*$ let $\mathcal{A}(R, S)$ be the class of the $(0, 1)$-matrices with row sum R and column sum S. These matrices play an active role in modern mathematics and the applications extend from their natural context (Matrix Theory, Combinatorics or Graph Theory) to many other areas of knowledge as Biology or Chemistry. The Robinson-Schensted-Knuth correspondence establishes a bijection between the class $\mathcal{A}(R, S)$ and pairs of Young tableaux with conjugate shape λ and λ^* with $S \preceq \lambda \preceq R^*$. We give a canonical construction for matrices in $\mathcal{A}(R, S)$ whose insertion tableau has a prescribed shape λ, with $S \preceq \lambda \preceq R^*$. This algorithm generalizes some recent constructions due to R. Brualdi for the extremal cases $\lambda = S$ and $\lambda = R^*$.

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Talk 3. **Elementary matrices arising from unimodular rows**

Let $(R, \mathfrak{m})$ be a commutative local ring with maximal ideal $\mathfrak{m}$. Let $A = R[X]$ be a R-algebra and f be a monic polynomial of $R[X]$. Assume that

1. A/fA is finitely generated R-module.
2. $R(X)$ contains a subalgebra B such that $R(X) = R[X] + B$ and $\mathfrak{m}B \subset J(B)$ (the Jacobson radical of B).
3. $SL_r(K(X)) = E_r(K(X))$ for every $r \geq 1$, where $K = R/m$.
4. $SL_n(R[X]) \cap E_n(R(X)) = E_n(R[X])$.

Let $F = (f_1, f_2, \ldots, f_n)$ be a unimodular row in $R[X]$ which can be completed to a matrix C_1 belonging to $E_n(R(X))$ and a matrix C_2 belonging to $E_n(K[X])$. Then F can also be completed to a matrix belonging to $E_n(R[X])$.

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Talk 4. **Nonsingular ACI-matrices over integral domains**

An ACI-matrix is a matrix whose entries are polynomials of degree at most one in a number of indeterminates where no indeterminate appears in two different columns. Consider the next two problems: (a) characterize the ACI-matrices of order n all of whose completions have the same nonzero constant determinant; (b) characterize the ACI-matrices of order n all of whose completions are nonsingular. In 2010 Brualdi, Huang and Zhan solved both problems for fields of at least $n + 1$ elements. We extend their result on problem (a) to integral domains, and extend their result on problem (b) to arbitrary fields.

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CP 17. Lyapunov equations

Talk 1. **Lyapunov matrix inequalities with solutions sharing a common Schur complement**

The square matrices $A_1, A_2, \cdots, A_N$ are said to be stable with respect of the positive definite matrices $P_1, \cdots, P_N$ if the Lyapunov inequalities $A_i^T P_i + P_i A_i < 0$, with $i = 1, \cdots, N$, are satisfied. In this case, the matrices P_i are called Lyapunov solutions for the matrices A_i, with $i = 1, \cdots, N$, respectively. In this work, we investigate when the Lyapunov solutions P_i share the same Schur complement of certain order. The existence problem of a set of Lyapunov solutions sharing a common Schur complement arises, for instance, in the stabilization of a switched system, under arbitrary switching signal for which discontinuous jumps on some of the state components are allowed, during the switching instants.

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Talk 2. **Solving large scale projected periodic Lyapunov equations using structure-exploting methods**

Simulation and analysis of periodic systems can demand to solve the projected periodic Lyapunov equations associated with those periodic systems, if the periodic systems are in descriptor forms. In this talk, we discuss the iterative solution of large scale sparse projected periodic discrete-time algebraic Lyapunov equations which arise in periodic state feedback problems and in model reduction of periodic descriptor systems. We extend the Smith method to solve the large scale projected periodic discrete-time algebraic Lyapunov equations in lifted form. The block diagonal structure of the periodic solution is preserved in every iteration steps. A low-rank version of this method is also presented, which can be used to compute low-rank approximations to the solutions of projected periodic discrete-time algebraic Lyapunov equations. Numerical results are given to illustrate the efficiency and accuracy of the proposed method.

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Talk 3. **A new minimal residual method for large scale Lyapunov equations**

The solution of large scale algebraic Lyapunov equations is important in the stability analysis of linear dynamical systems. We present a projection-based residual minimizing procedure for solving the Lyapunov equation.As opposed to earlier methods (e.g.,[I.M. Jiamoukha and E.M. Kasenally, SIAM J. Numer.Anal., 1994]), our algorithm relies on an inner iterative solver, accompanied with a selection of preconditioning techniques that effectively exploit the structure of the problem. The residual minimization allows us to relax the coefficient matrix passivity constraint, which is sometimes hard to meet in real application problems. Numerical experiments with standard benchmark problems will be reported.

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Talk 4. **Contributions to the analysis of the extended Krylov subspace method (EKSM) for Lyapunov matrix equations**

The EKSM is an iterative method which can be used to approximate the solution of Lyapunov matrix equations and extract reduced order models of linear time invariant systems (LTIs). We explain why any positive residual curve is possible and we show how to construct LTIs for which the approximations of the Gramians returned by the EKSM are orthogonal in exact arithmetic. Finally, we build an electrical circuit for which the Gramians P and Q satisfy $\mathrm{fl}(P\,\mathrm{fl}(Qx)) = 0$, where $\mathrm{fl}(x)$ denotes the floating point representation of x.

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CP 18. Eigenvalue problems II

Talk 1. **Differentials of eigenvalues and eigenvectors under nonstandard normalizations with applications**

We propose a new approach to the identification of the change in eigenvalues and eigenvectors as a consequence of a perturbation applied to the eigenproblem. The approach has three differences with respect to most previous literature that allow for covering several intricate normalizations previously adopted and simplify the proofs. First, we start from the differentials, and not from the derivatives. Second, in our more general result, we explicitly consider two normalization functions, one for the right and one for the left eigenvector. Third, using complex differentials, we explicitly allow for nonanalytic normalization functions. Several applications are discussed in detail.

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Talk 2. **A solution to the inverse eigenvalue problem for certain singular Hermitian matrices**

We present the solution to Inverse Eigenvalue problem of certain singular Hermitian matrices by developing a method in the context of consistency conditions, for solving the direct Eigenvalue problem for singular matrices. Based on this method, we propose an algorithm to reconstruct such matrices from their eigenvalues. That is, we develop algorithms and prove that they solve special $2 \times 2, 3 \times 3$ and 4×4 singular symmetric matrices. In each case, the number of independent matrix elements would reduce to the extent that there would an isomorphism between the seed elements and the eigenvalues. We also initiate a differential geometry and, a numerical analytic interpretation of the Inverse Eigenvalue problem using fiber bundle with structure group O(n). A simple and more practicable algorithm based on the Newtons iterative method would be developed to construct symmetric matrices using singular symmetric matrices as the initial matrices.

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Talk 3. **Divide and conquer the CS decomposition**

The CS decomposition factors a unitary matrix into simpler components, revealing the principal angles between certain linear subspaces. We present a divide-and-conquer algorithm for the CS decomposition and the closely related generalized singular value decomposition. The method is inspired by the work of Gu and Eisenstat and others. Novel representations enforce orthogonality.

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Talk 4. **The optimal perturbation bounds of the Moore-Penrose inverse under the Frobenius norm**

We obtain the optimal perturbation bounds of the Moore-Penrose inverse under the Frobenius norm by using Singular Value Decomposition, which improved the results in the earlier paper [P.-Å.Wedin, Perturbation theory for pseudo-inverses, BIT 13 (1973) 217-232]. In addition, a perturbation bound of the Moore-Penrose inverse under the Frobenius norm in the case of the multiplicative perturbation model is also given.

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CP 19. Positivity I

Talk 1. **Positivity preserving simulation of differential-algebraic equations**

We discuss the discretization of differential-algebraic equations with the property of positivity, as they arise e.g. in chemical reaction kinetics or process engineering. For index-1 problems, in which the differential and algebraic equations are explicitly given, we present conditions for a positive numerical approximation that also meets the algebraic constraints. These results are extended to higher index problems, i.e., problems in which some algebraic equations are hidden in the system, by a positivity preserving index reduction. This remodeling procedure filters out the hidden constraints without destroying the positivity property and admits to trace back these systems to the index-1 case.

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Talk 2. **Computing the exponentials of essentially nonnegative matrices with high relative accuracy**

In this talk we present an entry-wise forward stable algorithm for computing the exponentials of essentially nonnegative matrices (Metzler matrices). The algorithm is a scaling-and-squaring approach built on Taylor expansion and non-diagonal Padé approximation. As an important feature, we also provide an entry-wise error estimate to the user. Both rounding error analysis and numerical experiments demonstrate the stability of the new algorithm.

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Talk 3. **Sparse and unique nonnegative matrix factorization through data preprocessing**

Nonnegative matrix factorization (NMF) has become a very popular technique in data mining because it is able to extract meaningful features through a sparse and part-based representation. However, NMF has the drawback of being highly ill-posed and there typically exist many different but equivalent factorizations. In this talk, we introduce a preprocessing technique leading to more well-posed NMF problems whose solutions are sparser. It is based on the theory of M-matrices and the geometric interpretation of NMF, and requires to solving constrained linear least squares problems. We theoretically and experimentally demonstrate the effectiveness of our approach.

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Talk 4. **Iterative regularized solution of linear complementarity problems**

For Linear Complementarity Problems (LCP) with a positive semidefinite matrix M, iterative solvers can be derived by a process of regularization. In [R. W. Cottle et al., The LCP, Academic Press, 1992] the initial LCP is replaced by a sequence of positive definite ones, with the matrices $M + \alpha I$. Here we analyse a generalization of this method where the identity I is replaced by a positive definite diagonal matrix D. We prove that the sequence of approximations so defined converges to the minimal D-norm solution of the initial LCP. This extension opens the possibility for interesting applications in the field of rigid multibody dynamics.

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CP 20. Control systems II

Talk 1. **Disturbance decoupling problem for singular switched linear systems**

In this paper, a geometric approach to disturbance decoupling problem for switched singular linear systems is made. A *switched singular linear system with disturbance* is a system which consists of several linear subsystems with disturbance and a piecewise constant map σ taking values into the index set $M = \{1, \ldots, \ell\}$ which indexes the different subsystems. In the continuous case, such a system can be mathematically described by $E_\sigma \dot{x}(t) = A_\sigma x(t) + B_\sigma u(t) + G_\sigma g(t)$ where $E_\sigma, A_\sigma \in M_n(\mathbb{R})$, $B_\sigma \in M_{n\times m}(\mathbb{R})$, $G_\sigma \in M_{n\times p}(C)$ and $\dot{x} = dx/dt$. The term $g(t)$, $t \geq 0$, may represent modeling or measuring errors, noise, or higher order terms in linearization. In the case of standard state space systems the disturbance decoupling problem has been largely studied. The problem of constructing feedbacks that suppress this disturbance in the sense that $g(t)$ does not affect the input-output behaviour of the switched singular linear system with disturbance is analyzed and a solvability condition for the problem is obtained using invariant subspaces for singular switched linear systems.

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Talk 2. **Invariant subspaces of switched linear systems**

Invariant subspaces under a linear transformation were defined by von Neumann (1935) and generalized to linear dynamical systems: G. Basile and G. Marro (1969) defined the concept of controlled and conditioned invariant subspaces for control linear systems, I.M. Buzurovic (2000) studied (controlled and conditioned) invariant subspaces for singular linear systems. They are connected to a great number of disciplines, for example in the geometric study of control theory of linear time-invariant dynamical systems (in particular, controllability and observability). This notion was extended also to linear parameter-varying systems by introducing the concept of parameter-varying invariant subspaces. Recently, several authors such as A.A. Julius, A.J. van der Schaft, E. Yurtseven, W.P.M.H. Heemels, M.K. Çamlibel, among others, introduced invariant subspaces for switched linear systems (those containing any trajectory which originates on it) and applied them to different topics! , disturbance decoupling and observer design problems, for example. In this work we study properties and algorithms to determine the set of all invariant subspaces for a given switched linear system using linear algebra tools, providing a computational alternative to theoretical results.

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Talk 3. **On the pole placement problem for singular systems**

Let us consider a singular system with outputs
$E\dot{x} = Ax + Bu,\ y = Cx$, with
$E, A \in F^{h\times n}, B \in F^{h\times m}, C \in F^{p\times n}$. For r regular systems (E non singular), the pole assignment problem by state feedback, and by state feedback and output injection was solved a few decades ago. Recently, the pole assignment problem by state feedback has been solved for singular systems (E singular). We try to extend the solution to the pole assignment problem to singular systems by state feedback and output injection: Given a monic homogeneous polynomial $f \in F[x, y]$, we study the existence of a state feedback matrix F and an output injection K such that the state matrix $sE - (A + BF + KC)$ has f as characteristic polynomial, under a regularizability condition on the system.

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Talk 4. **Coordination control of linear systems**

Coordinated linear systems are particular hierarchical systems, characterized by conditional independence and invariance properties of the underlying linear spaces. Any distributed linear system can be transformed into a coordinated linear system, using observability decompositions. The motivation behind studying these systems is that some global control objectives can be achieved via local controllers: E.g., global stabilizability reduces to local stabilizability of all subsystems. The corresponding LQ problem separates into independent LQ problems on the lower level, and a more involved control problem on the higher level. For the latter problem, possible approaches include using subsystem observers, numerical optimization, and event-based feedback.

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CP 21. Matrix pencils

Talk 1. **Looking at the complexity index as a matrix measure**

In this paper we discuss a matrix measure based on a matrix norm. This measure, named complexity index, has been presented by Amaral et al., in 2007. In their study the authors consider that an economic system is represented by a square nonnegative matrix and their aim is to quantify complexity as interdependence in an IO system. However for large dimension matrices the computation of this complexity index is almost impossible. In order to contribute to a better perception of this measure in an economic context and to overcome this difficulty we present some properties and bounds for this index.

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Talk 2. **A matrix pencil tool to solve a sampling problem**
In sampling theory, the available data are often samples of some convolution operator acting on the function itself. In this talk we use the oversampling technique for obtaining sampling formulas involving these samples and having compactly supported reconstruction functions. The original problem reduces to finding a polynomial left inverse of a matrix pencil intimately related to the sampling problem. We obtain conditions for computing such reconstruction functions to be possible in a practical way when the oversampling rate is minimum. This solution is not unique, but there is no solution with fewer non-zero consecutive terms than the one obtained.

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Talk 3. **A duality relation for matrix pencils with applications to linearizations**
Let $A(x) = \sum_{i=0}^{d} A_i x^i$ be a $n \times n$ regular matrix polynomial, $Q \in \mathbb{C}^{(n+1)d,(n+1)d}$ the QR factor of

$$\begin{bmatrix} A_0 \\ A_1 \\ \vdots \\ A_d \end{bmatrix},$$

and Q_{SE} (resp. Q_{NE}) the $nd \times nd$ matrix obtained by removing the first n columns and the first (resp. last) n rows from Q. Then, $Q_{\mathrm{SE}} - xQ_{\mathrm{NE}}$ is a linearization of $A(x)$. This interesting result is a consequence of a new method for generating equivalent pencils, which is related to the so-called "pencil arithmetic" [Benner, Byers, '06]. This provides a new interesting framework for studying many known families of linearizations (Fiedler pencils, M^4 vector spaces). In the talk we present this technique and study the numerical stability of the QR-based linearization above.

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Talk 4. **Stability of reducing subspaces of a pencil**
Let $\lambda B - A$ be a pencil of $m \times n$ complex matrices. We call *reducing subspace* of the pencil $\lambda B - A$ to any subspace $\mathcal{N}$ of $\mathbb{C}^n$ such that

$$\dim(A\mathcal{N} + B\mathcal{N}) = \dim \mathcal{N} - \dim_{\mathbb{C}(\lambda)} \mathrm{Ker}(\lambda B - A)$$

where $\mathbb{C}(\lambda)$ is the field of rational fractions in λ (P. Van Dooren, 1983).
In this talk we analyze the existence of stable reducing subspaces of the pencil $\lambda B - A$, except for the case in which $\lambda B - A$ has only one column minimal index and only one row minimal index, and this last index is nonzero, as a complete system of invariants for the strict equivalence.

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CP 22. Matrix functions

Talk 1. **Improved Schur-Padé algorithm for fractional powers of a matrix**
We present several improvements to the Schur-Padé algorithm for computing arbitrary real powers A^s of a matrix $A \in \mathbb{C}^{n\times n}$ developed by the first two authors in [*SIAM J. Matrix Anal. Appl.*, 32 (2011), pp. 1056-1078]. We utilize an error bound in terms of the quantities $\|A^p\|^{1/p}$, for several small integers p, instead of $\|A\|$, extend the algorithm to allow real arithmetic to be used throughout when the matrix is real, and provide an algorithm that computes both A^s and the Fréchet derivative at A in the direction E at a cost no more than three times that for computing A^s alone. These improvements put the algorithm's development on a par with the latest (inverse) scaling and squaring algorithms for the matrix exponential and logarithm.

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Talk 2. **An automated version of rational Arnoldi for Markov matrix functions**
The Rational Arnoldi method is powerful one for approximating functions of large sparse matrices times a vector $f(A)v$ by means of Galerkin projection onto a subspace span $\{(A + s_1 I)^{-1}v, \ldots, (A + s_m I)^{-1}v\}$. The selection of asymptotically optimal shifts s_j for this method is crucial for its

convergence rate. We present and investigate a heuristic for the automated shift selection when the function to be approximated is of Markov type, $f(z) = \int_{-\infty}^{0} \frac{d\gamma(x)}{z-x}$, such as the matrix square root or other impedance functions. The performance of this approach is demonstrated at several numerical examples involving symmetric and nonsymmetric matrices.

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Talk 3. **Ranking hubs and authorities using matrix functions**
The notions of subgraph centrality and communicability, based on the exponential of the adjacency matrix of the underlying graph, have been effectively used in the analysis of undirected networks. In this talk we propose an extension of these measures to directed networks, and we apply them to the problem of ranking hubs and authorities. The extension is achieved by bipartization, i.e., the directed network is mapped onto a bipartite undirected network with twice as many nodes in order to obtain a network with a symmetric adjacency matrix. We explicitly determine the exponential of this adjacency matrix in terms of the adjacency matrix of the original, directed network, and we give an interpretation of centrality and communicability in this new context, leading to a technique for ranking hubs and authorities. The matrix exponential method for computing hubs and authorities is compared to the well known HITS algorithm, both on small artificial examples and on more realistic real-world networks. This is joint work with Michele Benzi (Emory University) and Ernesto Estrada (University of Strathclyde).

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Talk 4. **The geometric mean of two matrices from a computational viewpoint**
We consider the geometric mean of two matrices with an eye on computation. We discuss and analyze several numerical algorithms based on different properties and representations of the geometric mean and we show that most of them can be classified in terms of the rational approximations of the inverse square root function. Finally, a review of relevant applications is given.

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CP 23. Applications

Talk 1. **Study on efficient numerical simulation methods of dynamic interaction system excited via moving contact points**
When a railway train is travelling on the track, vehicles and the track are excited via moving contact points between wheels and a rail. A numerical simulation of this dynamic interaction is formulated to the problem of solving a large-scale, time-dependent linear or nonlinear system of equations. For the linear case, two methods of a direct method using the Sherman-Morrison-Woodbury formula and a PCG (Preconditioned Conjugate Gradient) method have been comparatively investigated. In the PCG method, by carrying out the Cholesky decomposition of the time-independent part of the coefficient matrix and constructing the preconditioner from it, a very efficient numerical simulation has been attained. In this talk, numerical simulation methods for nonlinear case will be also described.

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Talk 2. **A matrix version of a digital signature scheme based on pell equation**
Cryptography had been evolved by using different types of special matrices at Vandermonde matrix, febonasci Q-matrix, latin square etc. and based on these, various types of cryptosystems and digital signature scheme have been propsed. We apply the idea of Elleptic Curve Digital Signature Algorithm (ECDSA) on the solution space of Pell equation to designed digital signature scheme and then produce a matrix version of it. Also we compare the security of our signature and its matrix version to DSA and ECDSA. We show that the signature scheme based on Pell equation is more efficient than its analogue to elliptic curve i.e. ECDSA.

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Talk 3. **Evaluating computer vision systems**
As computer vision systems advance technologically and become more pervasive, the need for more sophisticated and effective methods to evaluate their accuracy grows. One method to evaluate the accuracy of a given computer vision system is to solve the "robot-world/hand-eye calibration problem" which has the form $\mathbf{AX} = \mathbf{YB}$ for unknown homogeneous matrices $\mathbf{X}$ and $\mathbf{Y}$. In this talk, I will present a closed-form solution to this problem using the Kronecker Product.

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CP 24. Preconditioning II

Talk 1. **Overlapping blocks by growing a partition with applications to preconditioning**
Starting from a partitioning of an edge-weighted graph into subgraphs, we develop a method which enlarges the respective sets of vertices to produce a decomposition with overlapping subgraphs. In contrast to existing methods, we propose that the vertices to be added when growing a subset are chosen according to a criterion which measures the strength of

connectivity with this subset. We obtain an overlapping decomposition of the set of variables which can be used for algebraic Schwarz preconditioners. Numerical results show that with these overlapping Schwarz preconditioners we usually substantially improve GMRES convergence when compared with preconditioners based on a non-overlapping decomposition, an overlapping decomposition based in adjacency sets without other criteria, or incomplete LU.

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Talk 2. **Communication avoiding ILU(0) preconditioner**

In this talk we present a general communication-avoiding Incomplete LU preconditioner for the system Ax = b, where communication-avoiding means reducing data movement between different levels of memory, in serial or parallel computation. We implement our method for ILU(0) preconditioners on matrices A that have a regular grid (2D 5-point stencil,...). The matrix A is reordered using nested dissection, then a special block and separator reordering is applied that allows to avoid communication. Finally, we show that our reordering of A does not affect the convergence rate of the ILU preconditioned systems as compared to the natural ordering of A, while it reduces data movement and improves the time needed for convergence.

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Talk 3. **Preconditioning for large scale μFE analysis of bone poroelasticity**

The mixed finite element discretization of Biot's model of poroelasticity in the displacement-flow-pressure ($\mathbf{u}$-$\mathbf{f}$-p) formulation leads to linear systems of the form

$$\begin{bmatrix} \mathbf{A}_{uu} & \mathbf{O} & \mathbf{A}_{pu}^T \\ \mathbf{O} & \mathbf{A}_{ff} & \mathbf{A}_{pf}^T \\ \mathbf{A}_{pu} & \mathbf{A}_{pf} & -\mathbf{A}_{pp} \end{bmatrix} \begin{bmatrix} \mathbf{u} \\ \mathbf{f} \\ \mathbf{p} \end{bmatrix} = \begin{bmatrix} \mathbf{g} \\ \mathbf{0} \\ \mathbf{b} \end{bmatrix}, \qquad (1)$$

where all diagonal blocks are positive definite. We solve (1) with MINRES and GMRES and preconditioners composed of AMG preconditioners for the individual diagonal blocks. We show optimality of the preconditioners and scalability of the parallel solvers. We also discuss more general inner-outer iterations.

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Talk 4. **Block-triangular preconditioners for systems arising from edge-preserving image restoration**

Signal and image restoration problems are often solved by minimizing a cost function consisting of an ℓ_2 data-fidelity term and a regularization term. We consider a class of convex and edge-preserving regularization functions. In specific, half-quadratic regularization as a fixed point iteration method is usually employed to solve this problem. We solve the above-described signal and image restoration problems with the half-quadratic regularization technique by making use of the Newton method. At each iteration of the Newton method, the Newton equation is a structured system of linear equations of a symmetric positive definite coefficient matrix, and may be efficiently solved by the preconditioned conjugate gradient method accelerated with the modified block SSOR preconditioner. The experimental results show that this approach is more feasible and effective than the half-quadratic regularization approach.

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CP 25. Tensors and multilinear algebra

Talk 1. **Decomposition of semi-nonnegative semi-symmetric three-way tensors based on LU matrix factorization**

CANDECOMP/PARAFAC (CP) decomposition of semi-symmetric three-way tensors is an essential tool in signal processing particularly in blind source separation. However, in many applications, such as magnetic resonance spectroscopy, both symmetric modes of the three-way array are inherently nonnegative. Existing CP algorithms, such as gradient-like approaches, handle symmetry and nonnegativity but none of them uses a Jacobi-like procedure in spite of its good convergence properties. First we rewrite the considered optimization problem as an unconstrained one. In fact, the nonnegativity constraint is ensured by means of a square change of variable. Second we propose a Jacobi-like approach using LU matrix factorization, which consists in formulating a high-dimensional optimization problem into several sequential rational subproblems. Numerical experiments emphasize the advantages of the proposed method, especially in the case of degeneracies such as bottlenecks.

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Talk 2. **Random matrices and tensor rank probabilities**

By combining methods for tensors (multiway arrays) developed by ten Berge and recent results by Forrester and Mays on the number of real generalised eigenvalues of real random matrices, we show that the probability for a real random Gaussian $n \times n \times 2$ tensor to be of real rank n is $P_n = (\Gamma((n+1)/2))^n/((n-1)!(n-2)!\dots 1!)$, where Γ is the gamma function, i.e., $P_2 = \pi/4$, $P_3 = 1/2$, $P_4 = 3^3\pi^2/2^{10}$, $P_5 = 1/3^2$, etc. [ref: G. Bergqvist, Lin. Alg. Appl. to appear, 2012 (doi:10.1016/j.laa.2011.02.041); G. Bergqvist and P. J. Forrester, Elect. Comm. in Probab. 16, 630-637, 2011]. Previously such probabilities were only studied using numerical simulations. We also show that for large n, $P_n = (e/4)^{n^2/4} n^{1/12} e^{-1/12-\zeta'(-1)}(1+O(1/n))$, where ζ is the Riemann zeta function.

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Talk 3. **A new truncation strategy for the higher-order singular value decomposition of tensors**

We present an alternative strategy to truncate the higher-order singular value decomposition (T-HOSVD) [De Lathauwer *et al.*, SIMAX, 2000]. Our strategy is called the sequentially truncated HOSVD (ST-HOSVD). It requires less operations to compute and often improves the approximation error w.r.t. T-HOSVD. In one experiment we performed, the results of a numerical simulation of a partial differential equation were compressed by T-HOSVD and ST-HOSVD yielding similar approximation errors. The execution time, on the other hand, was reduced from 2 hours 45 minutes for T-HOSVD to one minute for ST-HOSVD, representing a speedup of 133.

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Talk 4. **Probabilistic matrix approximation**

This talk will present new results from the computer vision domain. We define a probabilistic framework in which the full range of an incomplete matrix is approximated by incorporating a prior knowledge from similar matrices. Considering the low-rank matrix approximation inequality $\|\mathbf{A} - \mathbf{Q}\mathbf{Q}^T\mathbf{A}\| < \epsilon$, where the projection of $\mathbf{A}$ into the subspace spanned by $\mathbf{Q}$ is used as an approximation, the proposed framework derives $\mathbf{Q}$ having only a submatrix $\mathbf{A}(:, J)$ (*i.e.* given only a few columns) by utilizing a prior distribution $p(\mathbf{Q})$. Such an approach provides useful results in face recognition tasks when we deal with variations like illumination and facial expression.

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CP 26. Eigenvalue problems III

Talk 1. **Eigenvalues of matrices with prescribed entries**

An important motivation for our work is the description of the possible eigenvalues or the characteristic polynomial of a partitioned matrix of the form $A = [A_{i,j}]$, over a field, where the blocks $A_{i,j}$ are of type $p_i \times p_j$ $(i, j \in \{1, 2\})$, when some of the blocks $A_{i,j}$ are prescribed and the others are unknown. Our aim is to describe the possible list of eigenvalues of a partitioned matrix of the form $C = [C_{i,j}] \in F^{n \times n}$, where F is an arbitrary field, $n = p_1 + \cdots + p_k$, the blocks $C_{i,j}$ are of type $p_i \times p_j$ $(i, j \in \{1, \dots, k\})$, and some of its blocks are prescribed and the others vary. In this talk we provide some solutions for the following situations:
(i) $p_1 = \cdots = p_k$;
(ii) A diagonal of blocks is prescribed;
(iii) $k = 3$.

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Talk 2. **Characterizing and bounding eigenvalues of interval matrices**

In this talk we give a characterization of the eigenvalue set of an interval matrix and present some outer approximations on the eigenvalue set. Intervals represent measurement errors, estimation of unknown values or other kind of uncertainty. Taking into account all possible realizations of interval values is necessary to obtain reliable bounds on eigenvalues. This approach helps in robust stability checking of dynamical systems, and in many other areas, where eigenvalues of matrices with inexact entries are used.

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Talk 3. **Lifted polytopes methods for the computation of joint spectral characteristics of matrices**

We describe new methods for computing the joint spectral radius and the joint spectral subradius of arbitrary sets of matrices. The methods build on two ideas previously appeared in the literature:

the polytope norm iterative construction, and the lifting procedure. Moreover, the combination of these two ideas allows us to introduce a pruning algorithm which can importantly reduce the computational burden. We prove several appealing theoretical properties of our methods, and provide numerical examples of their good behaviour.

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CP 27. Multigrid I

Talk 1. **Algebraic multigrid for solution of discrete adjoint Reynolds-averaged Navier-Stokes (RANS) equations in compressible aerodynamics**

In this work, solution to the adjoint equations for second-order accurate unstructured finite volume discretizations of RANS equations is investigated. For target applications, the corresponding linear systems are very large and bad-conditioned, and finding an efficient solver for them is a challenging task. Here, we suggest a solution approach, based on algebraic multigrid (AMG), because AMG has potential for dealing with problems on unstructured grids. Combining AMG with defect correction helps to handle second-order accurate discretizations. The approach can be used in parallel, allowing solution of problems involving several million grid points, which we demonstrate on a number of test cases.

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Talk 2. **Symmetric multigrid theory for deflation methods**

In this talk we present a new estimate for the speed of convergence of deflation methods, based on the idea of Nicolaides, for the iterative solution of linear systems of equations. This is done by using results from classical algebraic multigrid theory. As a further result we obtain that many prolongation operators from multigrid methods can be used to span the deflation subspace, which is needed for deflation methods.

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Talk 3. **Aggregation-based multilevel methods for lattice QCD**

In this talk, we present a multigrid solver for application in Quantum Chromodynamics (QCD), a theory that describes the strong interaction between subatomic particles. In QCD simulations a substantial amount of work is spent in solving Dirac equations on regular grids. These large sparse linear systems are often ill conditioned and typical Krylov subspace methods (e.g. CGN, GCR, BiCGStab) tend to be slow. As a solution to their bad scaling behavior we present an aggregation based multigrid method with a domain decomposition smoother and show numerical results for systems up to the size of 450 million of unknowns.

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Talk 4. **Adaptive algebraic multigrid methods for Markov chains**

We present an algebraic multigrid approach for computing the stationary distribution of an irreducible Markov chain. This method can be divided into two main parts, namely a multiplicative bootstrap algebraic multigrid (BAMG) setup phase and a Krylov subspace iteration, preconditioned by the previously developed multigrid hierarchy. In our approach, we propose some modifications to the basic BAMG framework, e.g., using approximations to singular vectors as test vectors for the adaptive computation of the restriction and interpolation operators. Furthermore, new results concerning the convergence of the preconditioned Krylov subspace iteration for the resulting singular linear system will be shown.

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CP 28. Structured matrices II

Talk 1. **Structured matrices and inverse problems for discrete Dirac systems with rectangular matrix potentials**

Inverse problems for various classical and non-classical systems are closely related to structured operators and matrices. See, e.g., the treatment of such problems for discrete systems (where structured matrices appear) and additional references in A. Sakhnovich, *Inverse Problems* 22 (2006), 2083-2101 and a joint work of authors: *Operators and Matrices* 2 (2008), 201-231.

In this talk we consider an important case of discrete Dirac systems with rectangular matrix potentials and essentially develop in this way the results from the author's recent paper (see *Inverse Problems* 28 (2012), 015010) on continuous systems. The research was supported by the Austrian Science Fund (FWF) under Grant no. Y330. and German Research Foundation (DFG) under grant no. KI 760/3-1.

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Talk 2. **Applications of companion matrices**
Companion matrices are commonly used to estimate or compute polynomial zeros. We obtain new polynomial zero inclusion regions by considering appropriate polynomials of companion matrices, combined with similarity transformations. Our main tools are Gershgorin's theorem and Rouché's theorem: the former to show the way and the latter to prove the results.
In addition, our techniques uncover geometric aspects of Pellet's and related theorems about the separation of zeros that were apparently not noticed before. Along the way, we encounter nontrivial root-finding problems that are currently solved with heuristic methods. We briefly show how they can be solved without heuristics.

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Talk 3. **On factorization of structured matrices and GCD evaluation**
The paper gives a self-contained survey of fast algorithms for factorization of structured matrices. Algorithms of Sylvester- and Hankel-type are discussed. Sylvester-based algorithms reduce the required complexity of classical methods per one order and the Hankel-based algorithm keeps the same complexity with respect to the classical one, triangularizing the initial matrices in $O(n^2)$ flops. Their connections with the evaluation of GCD (Greatest common divisor) of two polynomials are demonstrated. The presented procedures are studied and compared in respect of their error analysis and complexity. Numerical experiments performed with a wide variety of examples show the effectiveness of these algorithms in terms of speed, stability and robustness.

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Talk 4. **An anti-triangular factorization of symmetric matrices**
Indefinite symmetric matrices occur in many applications, such as optimization, least squares problems, partial differential equations and variational problems. In these applications one is often interested in computing a factorization that puts into evidence the inertia of the matrix or possibly provides an estimate of its eigenvalues. In this talk we present an algorithm that provides this information for any symmetric indefinite matrix by transforming it to a block anti-triangular form using orthogonal similarity transformations. We show that the algorithm is backward stable and that it has a complexity that is comparable to existing matrix decompositions for dense indefinite matrices.

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CP 29. Miscellaneous IV

Talk 1. **Structure exploited algorithm for solving palindromic quadratic eigenvalue problems**
We study a palindromic quadratic eigenvalue problem (QEP) occurring in the vibration analysis of rail tracks under excitation arising from high speed train

$$(\lambda^2 A^T + \lambda Q + A)z = 0,$$

where $A, Q \in C^{n\times n}$ and $Q^T = Q$. The coefficient matrices Q and A have special structure: the matrix Q is block tridiagonal and block Toeplitz, and the matrix A has only one nonzero $q \times q$ block in the upper-right corner, where $n = mq$. In using the solvent approach to solve the QEP, we fully exploit the special structures of the coefficient matrices to reduce the $n \times n$ matrix equation $X + A^T X^{-1} A = Q$ into a $q \times q$ matrix equation of the same form. The numerical experiment is given to show that our method is more efficient and has better accuracy in computed results than existing methods.

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Talk 2. **A spectral multi-level approach for eigenvalue problems in first-principles materials science calculations**
We present a multi-level approach in Fourier space to solve the Kohn-Sham equations from Density Functional Theory (DFT) using a plane wave basis and replacing the ionic cores by pseudopotentials. By increasing the cutoff energy and associated other parameters in subsequent level, we demonstrate that this approach efficiently speeds up solving the Kohn-Sham equations. The method was implemented using the PARATEC first principles plane wave code. Examples of multi-level calculations for bulk silicon, quantum dots and an aluminum surface are presented. In some case using the multilevel approach the total computation time is reduced by over 50%. The connection to multigrid approachs in real space is also discussed.

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Talk 3. **Spectrum of Sylvester operators on triangular spaces of matrices**
We present recent results on the spectrum of the operator T given by $T(X) = AX + XB$ defined on spaces of matrices with triangular shape, e.g., block upper triangular matrices and other related spaces. We also discuss the spectrum of the multiplication operator $X \mapsto AXB$ on the same spaces.

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Talk 4. **Modulus-based successive overrelaxation method for pricing american options**
Since the Chicago Board Options Exchange started to operate in 1848, the trading of options has grown to tremendous scale and plays an important role in global economics. Various type of mathematical models for the prices of different kinds of options are proposed during the last decades, and the valuation of options has been topic of active research.
Consider the Black-Scholes model for American option, a high order compact scheme with local mesh refinement is proposed and analyzed. Then, Modulus-based successive overrelaxation method is taken for the solution of linear complementarity problems from discrete Black-Scholes American options model. The sufficient condition for the convergence of proposed methods is given. Numerical experiment further show that the high order compact scheme is efficient, and modulus-based successive overrelaxation method is superior to the classical projected successive overrelaxation method.

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CP 30. Iterative methods II

Talk 1. **On convergence of MSOR-Newton method for nonsmooth equations**
Motivated by [X.Chen, On the convergence of SOR methods for nonsmooth equations. Numer. Linear Algebra Appl. 9 (2002) 81-92], we further investigate a Modified SOR-Newton (MSOR-Newton) method for solving a system of nonlinear equations $F(x) = 0$, where F is strongly monotone, locally Lipschitz continuous but not necessarily differentiable. The convergence interval of the parameter in the MSOR-Newton method is given. Compared with SOR-Newton method, this interval can be larger and the algorithm can be more stable because of large denominator. Furthermore, numerical examples show that this MSOR-Newton method can converge faster than the corresponding SOR-Newton method by choosing a suitable parameter.

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Talk 2. **A framework for deflated BiCG and related solvers**
For solving ill-conditioned nonsymmetric linear algebraic systems, we introduce a general framework for applying augmentation and deflation to Krylov subspace methods based on a Petrov-Galerkin condition. In particular, the framework can be applied to the biconjugate gradient method (BICG) and some of its generalizations, including BiCGStab and IDR(s). Our abstract approach does not depend on particular recurrences and thus simplifies the derivation of theoretical results. It easily leads to a variety of realizations by specific algorithms. We avoid algorithmic details, but we show that for every method there are two approaches for extending it by augmentation and deflation.

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Talk 3. **Prescribing the behavior of the GMRES method and the Arnoldi method simultaneously**
In this talk we first show that the Ritz values generated in the subsequent iterations of the Arnoldi method can be fully independent from the eigenvalues of the input matrix. We will give a parametrization of the class of matrices and starting vectors generating prescribed Ritz values in all iterations. This result can be seen as an analogue of the parametrization that closed a series of papers by Arioli, Greenbaum, Pták and Strakoš (published in 1994, 1996 and 1998) on prescribing GMRES residual norm curves and spectra. In the second part of the talk we show, using the first part, that any GMRES convergence history is possible with any Ritz values in all iterations, provided we treat the GMRES stagnation case properly. We also present a parametrization of the class of matrices and right hand sides generating prescribed Ritz values and GMRES residual norms in all iterations.

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Talk 4. **Efficient error bounds for linear systems and rational matrix functions**
Does it make sense to run Lanczos on a (hermitian) tridiagonal matrix? This talk will give the answer 'yes'. If T is the tridiagonal matrix arising from the standard Lanczos process for the matrix A and a starting vector v, running Lanczos on the trailing $(2m + 1) \times (2m + 1)$ submatrix of T and with its start vector the $m + 1$st unit vector, we obtain information that allows to devise lower and upper bounds on the error of the Lanczos approximations to solutins of linear systems A^{-1} and, more generally, rational function evaluations $r(A)b$. The approach proceeds in a manner related to work of Golub and Meurant on the theory of moments and quadrature and allows in particular to

obtain upper error bounds, provided a lower bound on the spectrum is known. The computational work is very low and independent of the dimension of the matrix A. We will present several numerical results, including linear systems and rational approximations to the exponential and the sign function.

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CP 31. Direct methods

Talk 1. **On sparse threaded deterministic lock-free Cholesky and LDL^T factorizations**

We consider the design and implementation of sparse threaded deterministic Cholesky and LDL^T factorizations using lock-free algorithms. The approach is based on DAG representation of the factorization process and uses static scheduling mechanisms. Results show that the new solvers are comparable in quality to the existing nondeterministic ones with mean scalability degradation of about 15% over 150 instances from the University of Florida collection.

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Talk 2. **A fast algorithm for constructing the solution operator for homogeneous elliptic boundary value problems**

The large sparse linear system arising from the finite element or finite difference discretization of an elliptic PDE is typically solved with iterative methods such as GMRES or multigrid (often with the aid of a problem specific preconditioner). An alternative is solve the linear system directly via so-called nested dissection or multifrontal methods. Such techniques reorder the discretization nodes to reduce the asymptotic complexity of Gaussian elimination from $O(N^3)$ to $O(N^{1.5})$ for two dimensional problems, where N is the number of discretization points. By exploiting the structure in the dense matrices that arise in the computations (using, e.g., $\mathcal{H}$-matrix arithmetic) the complexity can be further reduced to $O(N)$. In this talk, we will demonstrate that such accelerated nested dissection techniques become particularly effective for homogeneous boundary value problems when the solution is sought on the boundary for several different sets of boundary data. In this case, a modified version of the accelerated nested dissection scheme can execute any solve beyond the first in $O(N_{\text{boundary}})$ operations, where N_{boundary} denotes the number of points on the boundary. Typically, $N_{\text{boundary}} \sim N^{0.5}$. Numerical examples demonstrate the effectiveness of the procedure for a broad range of elliptic PDEs that includes both the Laplace and Helmholtz equations.

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Talk 3. **Eliminate last variable first!**

When solving linear equations, textbooks typically start the elimination of variables from the top. We suggest, however, to start from the bottom, that is, we suggest to solve for the last variable from the last equation, and eliminate it from all other equations, then do the same for the second last equation, and so on. In particular, when solving the equilibrium equations arising from ergodic queueing systems, starting from the top can be proven to be unstable for large systems, whereas starting from the bottom is stable. Heuristic arguments show that starting from the bottom is also preferable in other cases.

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Talk 4. **Sharp estimates for the convergence rate of Orthomin(k) for a class of linear systems**

In this work we show that the convergence rate of Orthomin(k) applied to systems of the form $(I + \rho U)x = b$, where U is a unitary operator and $0 < \rho < 1$, is less than or equal to ρ. Moreover, we give examples of operators U and $\rho > 0$ for which the asymptotic convergence rate of Orthomin(k) is exactly ρ, thus showing that the estimate is sharp. While the systems under scrutiny may not be of great interest in themselves, their existence shows that, in general, Orthomin(k) does not converge faster than Orthomin(1). Furthermore, we give examples of systems for which Orthomin(k) has the same asymptotic convergence rate as Orthomin(2) for $k \geq 2$, but smaller than that of Orthomin(1). The latter systems are related to the numerical solution of certain partial differential equations.

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CP 32. Nonlinear methods

Talk 1. **On the performance of the algebraic optimized Schwarz methods with applications**

In this paper we investigate the performance of the algebraic optimized Schwarz methods. These methods are based on the modification of the transmission blocks. The transmission blocks are replaced by new blocks to improve the convergence of the corresponding algorithms. In the optimal case, convergence in two iterations can be achieved. We are interested in analyzing how the algebraic optimized Schwarz methods perform as preconditioners solving differential equations. We are also interested in their asymptotic behavior with respect to change in the problems parameters. We present different numerical simulations corresponding to different type of problems in two- and three-dimensions.

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Talk 2. **Optimizing additive Runge-Kutta smoothers for unsteady flow problems**

We consider the solution of unsteady flow problems using implicit time integration schemes. Typically the appearing nonlinear systems are solved using the FAS variant of multigrid, where the steady state algorithm is reused without changes. Significant speedup can be obtained by redesigning the multigrid method for unsteady problems. In this talk, we discuss possibilities of finding optimal smoothers from the class of additive Runge-Kutta schemes, using the linear advection diffusion equation as model problem. In particular, options for the target function are discussed, as the spectral radius of the smoother or the spectral radius of the multigrid iteration matrix.

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Talk 3. **On convergence conditions of waveform relaxation methods for linear differential-algebraic equations**

Waveform relaxation methods are successful numerical methods originated from the basic fixed-point idea in numerical linear algebra for solving time-dependent differential equations, which was first introduced for simulating the behavior of very large electrical networks. For linear constant-coefficient differential-algebraic equations, we study the waveform relaxation methods without demanding the boundedness of the solutions based on infinite time interval. In particular, we derive explicit expressions and obtain asymptotic convergence rates of this class of iteration schemes under weaker assumptions, which may have wider and more useful application extent. Numerical simulations demonstrate the validity of the theory.

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Talk 4. **On sinc discretization and banded preconditioning for linear third-order ordinary differential equations**

Some draining or coating fluid-flow problems and problems concerning the flow of thin films of viscous fluid with a free surface can be described by third-order ordinary differential equations. In this talk, we solve the boundary value problems of such equations by sinc discretization and prove that the discrete solutions converge to the true solutions of the ordinary differential equations exponentially. The discrete solution is determined by a linear system with the coefficient matrix being a combination of Toeplitz and diagonal matrices. The system can be effectively solved by Krylov subspace iteration methods such as GMRES preconditioned by banded matrices. We demonstrate that the eigenvalues of the preconditioned matrix are uniformly bounded within a rectangle on the complex plane independent of the size of the linear system. Numerical examples are given to illustrate the effective performance of our method.

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CP 33. Matrices and graphs

Talk 1. **Complex networks metrics for software systems**

The study of large software systems has recently benefited from the application of complex graph theory. In fact, it is possible to describe a software system by a complex network, where nodes and edges represent software modules and the relationships between them, respectively. In our case, the goal is to study the occurrence of bugs in the software development and to relate them to some metrics, either old or recently introduced, used to characterize the nodes of a graph. This will be done through the application of numerical linear algebra techniques to the adjacency matrix associated to the graph.

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Talk 2. **On Euclidean distance matrices of graphs**

A matrix $D \in \mathbb{R}^{n\times n}$ is *Euclidean distance matrix (EDM)*, if there exist points $\boldsymbol{x}_i \in \mathbb{R}^r$, $i = 1, 2, \ldots, n$, such that $d_{ij} = \|\boldsymbol{x}_i - \boldsymbol{x}_j\|^2$. Euclidean distance matrices have many interesting properties, and are used in various applications in linear algebra, graph theory, bioinformatics, e.g., where frequently a question arises, what can be said about a

configuration of points $\boldsymbol{x}_i$, if only distances between them are known.
In this talk some results on Euclidean distance matrices, arising from the distances in graphs, will be presented. In particular, the distance spectrum of the matrices will be analysed for some families of graphs and it will be proven, that their distance matrices are EDM. A generalization to distance matrices of weighted graphs will be tackled.

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Talk 3. **Evaluating matrix functions by resummations on graphs: the method of path-sums**
We introduce the method of path-sums which is a tool for analytically evaluating a function of a square matrix, based on the closed-form resummation of infinite families of terms in the corresponding Taylor series. For finite matrices, our approach yields the exact result in a finite number of steps. We achieve this by combining a mapping between matrix powers and walks on a weighted graph with a universal result on the structure of such walks. This result reduces a sum over weighted walks to a sum over weighted paths, a path being forbidden to visit any vertex more than once.

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Talk 4. **An estimation of general interdependence in an open linear structure**
The open linear structures have many applications in sciences. Especially, the social sciences - including economics - have made extensive use of them.
Starting from the biunivocal correspondence between a square matrix and a graph, this paper aims to establish several theorems linking components, sub-structures, loops and circuits of the graph with certain characteristics of the exchange matrix. That correspondence focuses particularly on the determinant of the matrix and its sub-matrices. Hence, the determinant is a specific function of the possible arrangements in the graph (open, closed, linear, triangular, circular, autarkic, etc.).
A matrix appears as an orderly and intelligible articulation of sub-structures, themselves divisible until elementary coefficients. Hence it comes a possible measure of general interdependence between the elements of a structure. Multiple uses can be deduced (inter-industry trade, international trade, strategic positioning, pure economic theory, etc.).

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CP 34. PageRank

Talk 1. **On the complexity of optimizing PageRank**
We consider the PageRank Optimization problem in which one seeks to maximize (or minimize) the PageRank of a node in a graph through adding or deleting links from a given subset. The problem is essentially an eigenvalue maximization problem and has recently received much attention. It can be modeled as a Markov Decision Process. We provide provably efficient methods to solve the problem on large graphs for a number of cases of practical importance and we show using perturbation analysis that for a close variation of the problem, the same techniques have exponential worst case complexity.

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Talk 2. **Optimization of the HOTS score of a website's pages**
Tomlin's HOTS algorithm is one of the methods allowing search engines to rank web pages, taking into account the web graph structure. It relies on a scalable iterative scheme computing the dual solution (the HOTS score) of a nonlinear network flow problem. We study here the convergence properties of Tomlin's algorithm as well as of some of its variants. Then, we address the problem of optimizing the HOTS score of a web page (or site), given a set of controlled hyperlinks. We give a scalable algorithm based on a low rank property of the matrix of partial derivatives of the objective function and report numerical results on a fragment of the web graph.

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Talk 3. **An inclusion set for the personalized PageRank**
The Personalized Page Rank (PPR) was one of the first modifications introduced to the original formulation of the PageRank algorithm. PPR is based on a probability distribution vector that bias the PR to some nodes. PPR can be used as a centrality measure in complex networks. In this talk, we give some theoretical results for the PPR considering a directed graph with dangling nodes (nodes with zero out-degree). Our results, derived by using matrix analysis, lead to an inclusion set for the entries of the PPR. These bounds for the PPR, for a given distribution for the dangling nodes, are independent of the personalization vector. We use these results to give a theoretical

justification of a recent model that uses the PPR to classify users of Social Network Sites. We give examples of how to use these results in some networks.

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CP 35. Matrix equations

Talk 1. **Upper bounds on the solution of the continuous algebraic Riccati matrix equation**

In this, paper, by considering the equivalent form of the continuous algebraic Riccati matrix equation and using matrix properties ans inequalities, we propose new upper matrix bounds for the solution of the continuous algebraic Riccati matrix equation. Then, we give numerical examples to show the effectiveness of our results.

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Talk 2. **A large-scale nonsymmetric algebraic Riccati equation from transport theory**

We consider the solution of the large-scale nonsymmetric algebraic Riccati equation $XCX - XD - AX + B = 0$ from transport theory (Juang 1995), with $M \equiv [D, -C; -B, A] \in \mathbb{R}^{2n\times 2n}$ being a nonsingular M-matrix. In addition, A, D are rank-1 corrections of diagonal matrices, with the products $A^{-1}u$, $A^{-\top}u$, $D^{-1}v$ and $D^{-\top}v$ computable in $O(n)$ complexity, for some vectors u and v, and B, C are rank 1. The structure-preserving doubling algorithm by Guo, Lin and Xu (2006) is adapted, with the appropriate applications of the Sherman-Morrison-Woodbury formula and the sparse-plus-low-rank representations of various iterates. The resulting large-scale doubling algorithm has an $O(n)$ computational complexity and memory requirement per iteration and converges essentially quadratically, as illustrated by the numerical examples.

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Talk 3. **A stable variant of the biconjugate A-orthogonal residual method for non-Hermitian linear systems**

We describe two novel iterative Krylov methods, the biconjugate A-orthogonal residual (BiCOR) and the conjugate A-orthogonal residual squared (CORS) methods, developed from variants of the nonsymmetric Lanczos algorithm. We discuss both theoretical and computational aspects of the two methods. Finally, we present an algorithmic variant of the BiCOR method which exploits the composite step strategy employed in the development of the composite step BCG method, to cure one of the breakdowns called as pivot breakdown. The resulting interesting variant computes the BiCOR iterates stably on the assumption that the underlying Biconjugate A-orthonormalizaion procedure does not break down.

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Talk 4. **On Hermitian and skew-Hermitian splitting iteration methods for the equation** $AXB = C$

In this talk we present new results on iteration method for solving the linear matrix equation $AXB = C$. This method is formed by extending the corresponding HSS iterative methods for solving $Ax = b$. The analysis shows that the HSS iteration method will converge under certain assumptions. Moreover, the optimal parameter of this iteration method is presented in the latter part of this paper. Numerical results for the new method show that this new method is more efficient and robust compared with the existing methods.

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CP 36. Positivity II

Talk 1. **A note on B-matrices and doubly B-matrices**

A matrix with positive row sums and all its off-diagonal elements bounded above by their corresponding row means was called in *Peña, J.M., A class of P-matrices with applications to the localization of the eigenvalues of a real matrix, SIAM J. Matrix Anal. Appl. 22, 1027-1037 (2001)* a B-matrix. In *Peña, J.M., On an alternative to Gerschgorin circles and ovals of Cassini, Numer. Math. 95, 337–345 (2003)*, the class of doubly B-matrices was introduced as a generalization of the previous. In this talk we present several characterizations and properties of these matrices and for each of these classes we consider corresponding questions for subdirect sums of two matrices (a general 'sum' of matrices introduced by S.M. Fallat and C.R. Johnson, of which the direct sum and ordinary sums are special cases).

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Talk 2. **Accurate computations for rational Bernstein-Vandermonde and Said-Ball-Vandermonde matrices**

Gasca and Peña showed that nonsingular totally nonnegative (TNN) matrices and its inverses admit a bidiagonal decomposition. Koev, in a recent work, assuming that the bidiagonal decompositions of a TNN matrix and its inverse are known with high relative accuracy (HRA), presented algorithms for performing some algebraic computations with high relative accuracy: computing the eigenvalues and the singular values of the TNN matrix, computing the inverse of the TNN matrix and obtaining the solution of some linear systems whose coefficient matrix is the TNN matrix.

Rational Bernstein and Said-Ball bases are usual representations in Computer Aided Geometric Design (CAGD). Solving some of the algebraic problems mentioned above for the collocations matrices of those bases (RBV and RSBV matrices, respectively) is important for some problems arising in CAGD. In our talk we will show how to compute the bidiagonal decomposition of the RBV and RSBV matrices with HRA. Then we will apply Koev's algorithms showing the accuracy of the obtained results for the considered algebraic problems.

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Talk 3. **On properties of combined matrices**

The combined matrix of a nonsingular matrix A is the Hadamard (entry wise) product $A \circ \left(A^{-1}\right)^T$. It's well known that all row (column) sums of combined matrices are constant and equal to one. Recently, some results on combined matrices of various classes of matrices has been done in LAA-430 (2009) and LAA-435 (2011). In this work, we analyze similar properties (characterizations, positiveness, spectrum) when the matrix A belongs to some kind of matrices.

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Talk 4. **Computing the Jordan blocks of irreducible totally nonnegative matrices**

In 2005 Fallat and Gekhtman fully characterized the Jordan Canonical Form of the irreducible totally nonnegative matrices. In particular, all nonzero eigenvalues are simple and the possible Jordan structures of the zero eigenvalues are well understood and described. Starting with the bidiagonal decomposition of these matrices, we present an algorithm for computing all the eigenvalues, including the Jordan blocks, to high relative accuracy in what we believe is the first example of Jordan structure being computed accurately in the presence of roundoff errors.

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CP 37. Matrix computations

Talk 1. **Computation of the matrix pth root and its Fréchet derivative by integrals**

We present new integral representations for the matrix pth root and its Fréchet derivative and then investigate the computation of these functions by numerical quadrature. Three different quadrature rules are considered: composite trapezoidal, Gauss-Legendre and adaptive Simpson. The problem of computing the matrix pth root times a vector without the explicit evaluation of the pth root is also analyzed and bounds for the norm of the matrix pth root and its Fréchet derivative are derived.

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Talk 2. **An algorithm for the exact Fisher information matrix of vector ARMAX time series processes**

In this paper an algorithm is developed for the exact Fisher information matrix of a vector ARMAX Gaussian process, VARMAX. The algorithm is composed by recursion equations at a vector-matrix level and some of these recursions consist of derivatives. For that purpose appropriate differential rules are applied. The derivatives are derived from a state space model for a vector process. The chosen representation is such that the recursions are given in terms of expectations of derivatives of innovations and not the process and observation disturbances. This enables us to produce an implementable algorithm for the VARMAX process. The algorithm will be illustrated by an example.

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Talk 3. **An algorithm to compute the matrix logarithm and its Fréchet derivative for use in condition number estimation**

Recently there has been a surge of interest in the logarithm from within the finance, control and machine learning sectors. We build on work by Al-Mohy and Higham to give an algorithm for computing the matrix logarithm and its Fréchet derivative simultaneously. We will show that the new algorithm is significantly more efficient than existing alternatives and explain how it can be used to estimate the condition number of the logarithm. We also derive a version of the algorithm that works entirely in real arithmetic where appropriate.

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Talk 4. **High-order iterative methods for the matrix pth root**
The main goal of this paper is to approximate the principal p-th root of a matrix by high-order iterative methods. We analyse the semilocal convergence and the speed of convergence of these methods. Concerning stability, it is well known that even the simplified Newton iteration is unstable. Despite it, we are able to present stable versions of our algorithms. Finally, we test numerically the methods. We check the numerical robustness and stability of the methods by considering matrices that are close to be singular and are badly conditioned. We find algorithms in the family with better numerical behavior than both Newton and Halley methods. These two last algorithms are basically the iterative methods proposed in the literature to solve this problem.

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CP 38. Eigenvalue problems IV

Talk 1. **An efficient way to compute the eigenvalues in a specific region of complex plane**
Spectral projectors are efficient tools for extracting spectral information of a given matrix or a matrix pair. On the other hand, these types of projectors have huge computational costs due to the matrix inversions needed by the most computation methods. The Gaussian quadratures can be combined with the sparse approximate inversion techniques to produce accurate and sparsity preserved spectral projectors for the computation of the needed spectral information. In this talk we will show how one can compute spectral projectors efficiently to find the eigenvalues in a specific region of the complex plane by using the proposed computational approach.

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Talk 2. **A divide, reduce and conquer algorithm for matrix diagonalization in computer simulators**
We present a new parallel algorithm for an efficient way to find a subset of eigenpairs for large hermitian matrices, such as Hamiltonians used in the field of electron transport calculations. The proposed algorithm uses a Divide, Reduce and Conquer (DRC) method to decrease computational time by keeping only the important degrees of freedom without loss of accuracy for the desired spectrum, using a black-box diagonalization subroutine (LAPACK, ScaLAPACK). Benchmarking results against diagonalization algorithms of LAPACK/ScaLAPACK will be presented.

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Talk 3. **A rational Krylov method based on Newton and/or Hermite interpolation for the nonlinear eigenvalue problem**
In this talk we present a new rational Krylov method for solving the nonlinear eigenvalue problem (NLEP):

$$A(\lambda)x = 0.$$

The method approximates $A(\lambda)$ by polynomial Newton and/or Hermite interpolation. It uses a companion-type reformulation to obtain a linear generalized eigenvalue problem (GEP). This GEP is solved by a rational Krylov method, where the number of iteration points is not fixed in advance. As a result, the companion form grows in each iteration. The number of interpolation points is dynamically chosen. Each iteration requires a linear system solve with $A(\sigma)$ where σ is the last interpolation point. We illustrate the method by numerical examples and compare with residual inverse iteration. We also give a number of scenarios where the method performs very well.

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Talk 4. **The rotation of eigenspaces of perturbed matrix pairs**
We present new $\sin\Theta$ theorems for relative perturbations of Hermitian definite generalized eigenvalue problem $A - \lambda B$, where both A and B are Hermitian and B is positive definite. The rotation of eigenspaces is measured in the matrix dependent scalar product. We assess the sharpness of the new estimates in terms of the effectivity quotients (the quotient of the measure of the perturbation with the estimator). The known $\sin\Theta$ theorems for relative perturbations of the single matrix Hermitian

eigenspace problem are included as special cases in our approach. We also present the upper bound for the norm of J-unitary matrix F ($F^*JF = J$), which plays important role in the relative perturbation theory for *quasi-definite* Hermitian matrices H, where $H_{qd} \equiv P^T HP = [H_{11}\,, H_{12}; H_{12}^*\,, -H_{22}]$ and $J = \mathrm{diag}(I_k, -I_{n-k})$, for some permutation matrix P and $H_{11} \in \mathbb{C}^{k\times k}$ and $H_{22} + H_{12}^* H_{11}^{-1} H_{12} \in \mathbb{C}^{n-k\times n-k}$ positive definite.

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CP 39. Probabilistic equations

Talk 1. **Banded structures in probabilistic evolution equations for ODEs**

Quite recently a novel approach to solve ODEs with initial conditions, using Probabilistic Evolution Equations which can be considered as the ultimate linearisation has been proposed and investigated in many details. One of the most important agents is the evolution matrix in this approach. The solution of the initial value problem of the infinite set of ODEs is basically determined by this matrix. The influence of the initial conditions is just specification of the initial point in infinite dimensional spac. If the evolution matrix has a banded structure then the solution can be constructed recursively and the convergence analysis becomes quite simplified.
In this presentation we focus on the triangular evolution matrices which have just two diagonals. The construction of the truncation approximants over finite submatrices and the convergence of their sequences will be focused on.

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Talk 2. **Space extensions in the probabilistic evolution equations of ODEs**

The evolution matrix appearing in the method, which has been recently developed and based on probabilistic evolution equations for the initial value problems of ODEs, can be controlled in structure at the expense of the dimension increase in the space. Certain function(s) of the unknown functions are deliberately added to the unknowns. This results in the simplification of the right hand side functions of the ODE(s). The basic features desired to be created in the evolution are triangularity and conicality to facilitate the construction of the solutions.
In this presentation we exemplify the utilization of the space extension to get the features mentioned above by focusing on the singularity and uniqueness issues.

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Talk 3. **Triangularity and conicality in probabilistic evolution equations for ODEs**

We have recently shown that all the explicit ordinary differential equations can be investigated through infinite linear ODE systems with a constant matrix coefficient (evolution matrix) under appropriately defined infinitely many initial conditions. The evolution matrix is the basic determinating agent for the characteristics of the solution. For a Taylor basis set it is in upper Hessenberg form which turns out to be triangular if the right hand side functions of the considered ODE(s) vanish at the expansion point. Even though the triangularity facilitates the analysis very much, the conicality, that is, the second degree multinomial right hand side structure is the best nontrivial case (linear case can be considered trivial in this perspective) to get simple truncation approximants. Talk will try to focus on these types of issues.

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CP 40. Control systems III

Talk 1. **$\mathcal{H}_2$ approximation of linear time-varying systems**

We consider the problem of approximating a linear time-varying $p \times m$ discrete-time state space model $\mathcal{S}$ of high dimension by another linear time-varying $p \times m$ discrete-time state space model $\widehat{\mathcal{S}}$ of much smaller dimension, using an error criterion defined over a finite time interval. We derive the gradients of the norm of the approximation error for the case with nonzero initial state. The optimal reduced order model is computed using a fixed point iteration. We compare this to the classical $\mathcal{H}_2$ norm approximation problem for the infinite horizon time-invariant case and show that our solution extends this to the time-varying and finite horizon case.

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Talk 2. **Analysis of behavior of the eigenvalues and eigenvectors of singular linear systems**

Let $E(p)\dot{x} = A(p)x + B(p)u$ be a family of singular linear systems smoothly dependent on a vector of real parameters $p = (p_1, \ldots, p_n)$. In this work we construct versal deformations of the given differentiable family under an equivalence relation, providing a special parametrization of space of systems, which can be effectively applied to perturbation analysis. Furthermore in particular, we study of behavior of a simple eigenvalue of a singular linear system family $E(p)\dot{x} = A(p)x + B(p)u$.

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Talk 3. **Stabilization of controllable planar bimodal linear systems**

We consider planar bimodal linear systems consisting of two linear dynamics acting on each side of a given hyperplane, assuming continuity along the separating hyperplane.
We obtain an explicit characterization of their controllability, which can be reformulated simply as $\det \mathcal{C}_1 \cdot \det \mathcal{C}_2 > 0$, where $\mathcal{C}_1, \mathcal{C}_2$ mean the controllability matrices of the subsystems. In particular, it is obvious from this condition that both subsystems must be controllable.
Moreover, this condition allows us to prove that both subsystems can be stabilized by means of the same feedback. In contrast to linear systems, the pole assignment is not achieved for bimodal linear systems and we can only assure the stabilization of these kind of systems.

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Talk 4. **A combinatorial approach to feedback equivalence of linear systems**

The feedback class of a reachable linear control system over a vector space is given by its Kronecker Invariants or equivalently by its Ferrers Diagram. We generalize the notion to a linear control system over a vector bundle (over a compact space) and obtain also a combinatorial invariant in a semigroup. Moreover we point out that this new invariant may be simplified by using algebraic K-theory.

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CP 41. Miscellaneous V

Talk 1. **Randomized distributed matrix computations based on gossiping**

We discuss new randomized algorithms for distributed matrix computations which are built on gossip-based data aggregation. In contrast to approaches where randomization in linear algebra algorithms is primarily utilized for approximation purposes, we investigate the *flexibility* and *fault tolerance* of *distributed* algorithms with randomized communication schedules. In our algorithms, each node communicates only with its neighborhood. Thus, they are attractive for decentralized and dynamic computing networks and they can heal from hardware failures occurring at runtime.
As case studies, we discuss distributed QR decomposition and distributed orthogonal iteration, their performance, their resilience to hardware failures, and the influence of asynchrony.

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Talk 2. **A tabular methodology for matrix Padé approximants with minimal row degrees**

In this paper we propose a tabular procedure to make easier the interpretation and application of a type of Matrix Padé Approximants associated to Scalar Component Models. The originality of these approximants lies in the concept of minimality defined and in the normalization associated. Considering matrix functions with k rows, to know the sets of minimal row degrees associated with an approximant, we study algebraic properties: it is relevant the number and the position of the linear depending rows that are in the block of the last k rows, in certain Hankel matrices. We illustrate this procedure with several examples.

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Talk 3. **Sublinear randomized algorithms for skeleton decompositions**

A skeleton decomposition is any factorization of the form $A = CUR$ where C comprises columns, and R comprises rows of A. Much is known on how to choose C, U, and R in complexity superlinear in the number of elements of A. In this paper we investigate the sublinear regime where much fewer elements of A are used to find the skeleton. Under an assumption of incoherence of the generating vectors of A (e.g., singular vectors), we show that it is possible to choose rows and columns, and find the middle matrix U in a well-posed manner, in complexity proportional to the cube of the rank of A up to log factors. Algorithmic variants involving rank-revealing QR decompositions are also discussed and shown to work in the sublinear regime.

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Talk 4. **Preconditioners for strongly non-symmetric linear systems**
Consider the system $Au = f$, where A is non-symmetric positive real matrix. The matrix A is decomposed in a sum of the symmetric matrix A_0 and the skew-symmetric A_1 matrix. When solving such linear systems, difficulties grow up because the coefficient matrices can lose the diagonal dominance property.
Consider the preconditioner (TPT)
$P = (B_C + \omega K_U)B_C^{-1}(B_C + \omega K_L)$, where
$K_L + K_U = A_1, K_L = -K_U^*$, $B_C = B_C^*$. We use TPT as preconditioner for GMRES (m) and BiCG methods and compare it with conventional SSOR preconditioner.
The standard 5-point central difference scheme on the regular mesh has been used for approximation of the convection-diffusion equation with Dirichlet boundary conditions. Numerical experiments of strongly nonsymmetric systems are presented.

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CP 42. Multigrid II

Talk 1. **Adaptive smoothed aggregation multigrid for nonsymmetric matrices**
We investigate algebraic multigrid (AMG) methods, in particular those based on the smoothed aggregation approach, for solving linear systems $Ax = b$ with a general, nonsymmetric matrix A. Recent results show that in this case it is reasonable to demand that the interpolation and restriction operators are able to accurately approximate singular vectors corresponding to the smallest singular values of A. Therefore, we present an extension of the *bootstrap AMG* setup, which is geared towards the singular vectors of A instead of the eigenvectors as in the original approach. We illustrate the performance of our method by considering highly nonsymmetric linear systems originating in the discretization of convection diffusion equations, which show that our algorithm performs very well when compared with established methods. In another series of numerical experiments, we present results which indicate that our method can also be used as a very efficient preconditioner for the *generalized minimal residual* (GMRES) method.

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Talk 2. **Local Fourier analysis for multigrid methods on semi-structured triangular grids**
Since the good performance of geometric multigrid methods depends on the particular choice of the components of the algorithm, the local Fourier analysis (LFA) is often used to predict the multigrid convergence rates, and thus to design suitable components. In the framework of semi-structured grids, LFA is applied to each triangular block of the initial unstructured grid to choose suitable local components giving rise to a block-wise multigrid algorithm which becomes a very efficient solver. The efficiency of this strategy is demonstrated for a wide range of applications. Different model problems and discretizations are considered.

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Talk 3. **Approach for accelerating the convergence of multigrid methods using extrapolation methods**
In this talk we present an approach for accelerating the convergence of multigrid methods. Multigrid methods are efficient methods for solving large problems arising the discretization of partial differential equations, both linear and nonlinear. In some cases the convergence may be slow (with some smoothers). Extrapolation methods are of interest whenever an iteration process converges slowly. We propose to formulate the problem as a fixed point problem and to accelerate the convergence of fixed-point iteration by vector extrapolation. We revisit the polynomial-type vector extrapolation methods and apply them in the MGLab software.

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Talk 4. **Algebraic multigrid (AMG) for saddle point systems**
We present a self-stabilizing approach to the construction of AMG for Stokes-type saddle point systems of the form

$$\mathcal{K} = \begin{pmatrix} A & B \\ B^T & -C \end{pmatrix}$$

where $A > 0$ and $C \geq 0$. Our method is purely algebraic and does not rely on geometric information.
We will show how to construct the interpolation and restriction operators $\mathcal{P}$ and $\mathcal{R}$ such that an inf-sup condition for $\mathcal{K}$ automatically implies an inf-sup condition for the coarse grid operator $\mathcal{K}^C = \mathcal{RKP}$. In addition, we give a two-grid convergence proof.

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