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An application of Hoffman graphs for spectral characterizations of graphs

In this work, we present the first application of Hoffman graphs for spectral characterizations of graphs. In particular, we show that the 2-clique extension of the $(t+1) \times (t+1)$-grid is determined by its spectrum when t is large enough. This result will help to show that the Grassmann graph $J_2(2D, D)$ is determined by its intersection numbers as a distance regular graph, if D is large enough.

This is joint work with J. Koolen and Q. Yang.

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Recent Applications of the Cauchon Algorithm to the Totally Nonnegative Matrices

The Cauchon algorithm, see, e.g., [3], has been applied to totally nonnegative matrices in order to characterize these matrices [3] and their subclasses [1], to recognize totally nonnegative matrix cells [4], and to derive determinatal criteria for this class of matrices [1]. In this joint work we report on some recent applications of this algorithm, e.g. to the study of invariance of total nonnegativity under entry-wise perturbation and the subdirect sum of two totally nonnegative matrices [2].

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This is joint work with Khawla Al Muhtaseb (Palestine Polytechnic University, Hebron, Palestine), Ayed Abdel Ghani (Palestine Polytechnic University, Hebron, Palestine), Shaun M. Fallat (University of Regina, Regina, SK, S4S 0A2 Canada), and Juergen Garloff (University of Applied Sciences / HTWG Konstanz, and University of Konstanz, Konstanz, Germany).

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Numerical study on combining the CGS-type methods and the residual smoothing technique

We treat the conjugate gradient squared (CGS)-type methods for solving large sparse nonsymmetric linear systems of equations. The conventional CGS method has large oscillations in the residual norms. In finite precision arithmetic, the large oscillations are known to affect the maximum attainable accuracy of the approximate solutions. Fokkema et al. have designed the CGS2 and the shifted CGS algorithms for improving the convergence of CGS; their convergence is often comparable to that of the bi-conjugate gradient stabilized (Bi-CGSTAB) method. Although the convergence behavior of CGS2 (or the shifted CGS) is less irregularly than that of CGS, its residual norms still oscillate.

The residual smoothing is known as a technique to obtain a smooth convergence behavior of the residual norms. However, with some existing implementations, Gutknecht and Rozložnik have analyzed that the attainable accuracy of the smoothed sequences is not higher than but the same level as that of the primary ones. In this talk, we give a new insight on combining the CGS-type methods and the residual smoothing technique, and we design smoothed variants of CGS-type for improving the attainable accuracy. In our alternative implementation of the residual smoothing, the primary and the smoothed sequences of residuals influence each other to avoid severe propagation of rounding errors. Numerical experiments demonstrate that the smoothed variants attain more accurate approximate solutions than do the underlying CGS-type methods.

This is joint work with Ryosuke Komeyama and Emiko Ishiwata.

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On matching in groups and vector spaces

A matching in an Abelian group G is a bijection f from a subset A to a subset B in G such that $a+f(a) \notin A$, for all $a \in A$. This notion was introduced by Fan and Losonczy who used matchings in $\mathbb{Z}^n$ as a tool for studying an old problem of Wakeford concerning elimination of monomials in a generic homogenous form under a linear change of variables . We show a sufficient condition for the existence of matchings in arbitrary groups and its linear analogue, which lead to some generalizations of the existing results in the theory of matchings in groups and central extensions of division rings. We introduce the notion of relative matchings between arrays of elements in groups and use this notion to study the behavior of matchable sets under group homomorphisms.

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Fredholm Properties of Toeplitz Operators on Fock Spaces

In this work we study the Fredholm property of Toeplitz operators T_f on classical Fock space F^p_α for $1 < p < \infty$ and $\alpha > 0$, with $f \in L^\infty(\mathbb{C})$ unbounded symbols. In particular, We investigate when these symbols are in VO and VMO spaces, we give necessary and sufficient conditions on these symbols for T_f to be Frdholm. We also succeeded to compute the index and to describe the essential spectrum for these Toeplitz operators. Furthermore, we study the boundedness and the copcatness of the block Toeplitz operator $T_\mathcal{A}$ on on the vector valued Fock spaces $(F^p_\alpha)_N$, with $\mathcal{A} \in L^\infty_{N\times N}(\mathbb{C})$ is a matrix valued function, and we characterize the Fredholm properties of $T_\mathcal{A}$ on this space with matrix function symbol $\mathcal{A}$ in $(L^\infty(\mathbb{C}) \cap VMO)_{N\times N}$ and $(L^\infty(\mathbb{C}) \cap VO)_{N\times N}$.

This is joint work with my supervisors Dr. Jani Virtanen and Dr. Titus Hilberdink.

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'Error Catastrophes' and the Information Content of the Perron vector in Quasispecies Models of Evolution

Eigen and Schuster in the 1970s introduced into evolutionary theory the concepts of the quasispecies, error threshold, and error catastrophe. The ideas gained traction in empirical virology and origin-of-life research, but in the process left much of their mathematical context behind. These concepts pertain to the derivatives of Perron vectors over families of linear dynamical systems that represent the processes of natural selection and mutation. One widely cited idea, the 'Eigen paradox', is that mutation limits the length of sequences that can be maintained by natural selection, and this limit prevents the evolution of longer sequences that would reduce the mutation rate. To address this paradox, a quantification of the information content of the Perron vector is used that reveals the independence of sequence length from information content, and also shows that information content is tied only loosely to the Perron root, which represents the mean fitness of the population at a stationary distribution. The convexity of the Perron root as a function of mutation rate is proven over arbitrary selection regimes, which implies that an 'error catastrophe' never corresponds to a precipitous drop in the Perron root, but rather the opposite – a slowing in the rate of decay of fitness with mutation rate.

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A lower bound for the energy of symmetric matrices and graphs

The energy of a symmetric matrix is the sum of the absolute values of its eigenvalues. We introduce a lower bound for the energy of a symmetric partitioned matrix into blocks. This bound is related to the spectrum of its quotient matrix. Furthermore, we study necessary conditions for the equality. Applications to the energy of the generalized composition of a family of arbitrary graphs are obtained. A lower bound for the energy of a graph with a bridge is given. Some computational experiments are presented in order to show that, in some cases, the obtained lower bound is incomparable with the well known lower bound $2\sqrt{m}$, where m is the number of edges of the graph.

This is joint work with Maria Robbiano and B. San Martin. This work was supported by Portuguese Foundation for Science and Technology through CIDMA - Center for Research and Development in Mathematics and Applications, within project UID/MAT/04106/2013.

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Solving Linear Systems: Reconstructing Unknowns to Interpret Row Reduced Matrices

The origins of linear algebra lie in efforts to solve systems of linear equations and understand the nature of their solution sets. Solving linear systems and interpreting their solution sets in fact can entail hidden and significant challenges for students that are important for their later success in linear algebra, as well as their work in related STEM courses. This talk examines final exam data from 69 students in an introductory undergraduate linear algebra course at a large public university in the southwestern US. Findings suggest that students are largely successful in representing systems of linear equations using augmented matrices, but that interpreting the row reduced echelon form of these matrices is a common source of difficulty, particularly when the number of equations differs from the number of unknowns.

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Matricial and numerical ranges in the classification of small-dimension operator systems

Operator systems are unital, selfadjoint subspaces of $B(H)$, where one considers unital completely positive maps as their morphisms. While an abstract characterization of these spaces has been known for 40 years (since Choi-Effros), the isomorphism problem is intractable even for 3-dimensional operator systems. We will outline the general theory and describe some characterizations of isomorphisms in concrete examples.

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The population dynamics of a fish species subject to environmental stochasticity

Arctic char is a salmonid. Of particular importance here are populations living in rivers tributary of Cambridge Bay, in the Canadian High Arctic, for which we have capture data provided by the Freshwater Institute in Winnipeg. Chars have a complicated life cycle: contrary to salmons, they are known to reproduce several times during their life; they also show limited homing behaviour. I will present a model for the life-cycle of arctic char and the corresponding species population dynamics. I will investigate in particular the role of climate-induced variations of survival, which will result in inhomogeneous products of matrices.

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A Leslie matrix model for Sicyopterus lagocephalus in La Réunion: sensitivity, uncertainty and research prioritization

We describe a deterministic Leslie matrix model for the population dynamics of S. lagocephalus in La Réunion. The model has fours stages and is periodic. The stages (sea + three river sites) describe the amphidromous nature of the species. A 12-month periodicity captures the seaonality in the life course. A baseline scenario is established with plausible age-specific fecundity and survival rates for which the dominant eigenvalue of the year-on-year projection matrix is 1. Large uncertainties on the parameter values preclude the use of the model for management purpose. A sensitivity/uncertainty analysis shed light on the parameters that cause much of the output to vary and that are poorly known: mortality at sea, at river mouths due to fishing, and in the rivers.

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Estimating Eigenvalue Distributions

We consider the problem of estimating the distribution of eigenvalues of an Hermitian matrix. We review and compare various numerical methods for approaching this problem and examine their application to the problem of load balancing for spectrum slicing eigensolvers in a high-performance computing environment.

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Mathematics for Musculoskeletal Diseases

We present two families of models done in collaboration with researchers at the University of Iowa Hospitals and Clinics: osteoarthritis and multiple-myeloma-induced bone disease. We provide an overview of the models, how they fit with the goals of our collaborators, and some computational results. We discuss our modeling choices with regards to the needs of our collaborators.

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Collaborative dictionary learning from big, distributed data

While distributed information processing has a rich history, relatively less attention has been paid to the problem of collaborative learning of nonlinear geometric structures underlying data distributed across sites that are connected to each other in an arbitrary topology. In this talk, we discuss this problem in the context of collaborative dictionary learning from big, distributed data. It is assumed that a number of geographically-distributed, interconnected sites have massive local data and they are interested in collaboratively learning a low-dimensional geometric structure underlying these data. In contrast to some of the previous works on subspace-based data representations, we focus on the geometric structure of a union of subspaces (UoS). In this regard, we propose a distributed algorithm, termed cloud K-SVD, for collaborative learning of a UoS structure underlying distributed data of interest. The goal of cloud K-SVD is to learn an overcomplete dictionary at each individual site such that every sample in the distributed data can be represented through a small number of atoms of the learned dictionary. Cloud K-SVD accomplishes this goal without requiring communication of individual data samples between different sites. In this talk, we also theoretically characterize deviations of the dictionaries learned at individual sites by cloud K-SVD from a centralized solution. Finally, we numerically illustrate the efficacy of cloud K-SVD in the context of supervised training of nonlinear classifiers from distributed, labeled training data.

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On a Feichtinger Problem for trace-class operators

About 15 years ago Hans Feichtinger asked whether non-negative trace-class integral operators with kernel in the modulation space M^1 admits a decomposition as a sum of non-negative rank-1 operators with generators having M^1-norms square-summable. In this talk we provide a negative answer to this question. This is a joint work with Kasso Okoudjou and Anirudha Poria.

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Squared distance matrix of a weighted tree

Let T be a tree with vertex set $\{1, \ldots, n\}$ such that each edge is assigned a nonzero weight. The squared distance matrix of T, denoted by Δ, is the $n \times n$ matrix with its $(i,j)-$element $d(i,j)^2$, where $d(i,j)$ is the sum of the weights of the edges on the (ij)-path. We obtain a formula for the determinant of Δ. A formula for Δ^{-1} is also obtained, under certain conditions. The results generalize known formulas for the unweighted case.

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On the spectra of multi-directed bipartite graphs

We define adjacency matrix as well as Laplacian matrix of a multi-digraph in a new way and describe the spectral properties of bipartite multi-digraphs. The complete spectrum of a multi-directed tree is derived in terms of the spectrum of the corresponding modular tree. In case of the Laplacian matrix of a multi-digraph, we obtain conditions for which the Laplacian matrix is singular. Finally, it is observed that the absolute values of the components of the eigenvectors corresponding to the second smallest eigenvalue of the Laplacian matrix of a multi-directed tree exhibit monotonicity property similar to the Fiedler vectors of an undirected graph.

This is joint work with Gopinath Sahu.

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Eisenstein series for hyperbolic reflection groups

We shall talk about some automorphic forms on real or complex hyperbolic space invariant under discrete subgroups of rank one real Lie groups $O(n,1)$ or $U(n,1)$. We are interested in a couple of examples in $O(25,1)$ and $U(13,1)$ where the discrete subgroups are automorphism groups of interesting hyperbolic lattices related to the Leech lattice. For $O(25,1)$ we get an infinite series $E(z,s)$ defined for $Re(s) > 25$. The series $E(z,s)$ is analogous to real analytic Eisenstein series and it can be analytically continued to $Re(s) > 25/2$. For $U(13,1)$ we get some automorphic forms that may play a role in uniformization of a complex ball quotient whose fundamental group is conjecturally related to the monster simple group.

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Asymptotics of determinants of block Toeplitz matrices

This talk will review what is known about the asymptotics of determinants of block Toeplitz matrices. (These matrices have constant matrix blocks on the diagonals.) While theorems for these asymptotic expansions are similar to the scalar case, in the block case the constants in the expansions are at times difficult to compute in an explicit way. The talk will describe methods that make this problem more tractable and some recent applications of the results to dimer models.

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A quantitative form of Schoenberg's theorem in fixed dimension

The Hadamard product of two matrices is formed by multiplying corresponding entries, and the Schur product theorem states that this operation preserves positive semidefiniteness.

It follows immediately that every analytic function with non-negative Maclaurin coefficients, when applied entrywise, preserves positive semidefiniteness for matrices of any order. The converse is due to Schoenberg: a function which preserves positive semidefiniteness for matrices of arbitrary order is necessarily analytic and has non-negative Maclaurin coefficients.

For matrices of fixed order, the situation is more interesting. This talk will present recent work which shows the existence of polynomials with negative leading term which preserve positive semidefiniteness, and characterises precisely how large this term may be.

This is joint work with D. Guillot (Delaware), A. Khare (Stanford) and M. Putinar (UC Santa Barbara and Newcastle). This work was supported by the American Institute of Mathematics and the International Centre for Mathematical Sciences, Edinburgh.

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Curves and envelopes that bound the spectrum of a matrix

The real part of any eigenvalue of a matrix A is less or equal to the largest eigenvalue of its Hermitian part H(A). Applied to exp(-iv)A for all v, the spectrum of A is also contained in an infinite intersection of v-rotated half-planes, an intersection that Johnson proved equals the numerical range F(A). Adam, Psarrakos and Tsatsomeros have shown that using the two largest eigenvalues of H(A), a cubic curve that restricts the location of eigenvalues can be constructed and, using the idea of rotations, the envelope of such cubic curves defines a region inside F(A) that still contains the spectrum. In contrast to F(A), the new region is not necessarily convex or connected. Here (see arXiv:1610.02196) we present a generalization of their method and show how new restricting curves for the spectrum can be found if one utilizes more than two eigenvalues of H(A), and how the envelopes of families of such curves bound new smaller regions for the spectrum.

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Another metric, another mean

The geometric mean of several positive definite matrices has been extensively studied in recent years, and has been much talked about in recent ILAS meetings. This mean is defined as the solution to a least squares problem with respect to a Riemannian metric on the space of positive definite matrices. There is another very interesting metric that gives rise to the Bures-Wasserstein distance much used in quantum information and in optimal transport. We will describe some features of this distance, and the associated two-variable and several-variable mean.

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Reality-based algebras with a 2-dimensional representation

We discuss how a 2-dimensional irreducible representation of a reality-based algebra (RBA), and in particular of an adjacency algebra of an association scheme, is determined by the other irreducible representations and their multiplicities. We apply this to classify the RBAs with a 2-dimensional representation, where all the other irreducible representations have multiplicity 1.

This is joint work with Angela Antonou.

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Some linear transformations associated with a tridiagonal pair of q-Racah type

Let V denote a finite-dimensional vector space. In this talk, we consider a tridiagonal pair A, A^* on V which has q-Racah type. Associated with A, A^* are several linear transformations which act on the split decompositions of V in an attractive way. We will introduce the associated linear transformations $\psi : V \to V$, $\Delta : V \to V$, and $\mathcal{M} : V \to V$. We mention that ψ can be used to obtain two actions of $U_q(\mathfrak{sl}_2)$ on V. Using these two actions, one can derive several useful relations involving the relevant linear transformations. We will use these relations to show that Δ can be factored into a q^{-1}-exponential in ψ times a q-exponential in ψ. We view Δ as a transition matrix from the first split decomposition of V to the second. Consequently, we view the q^{-1}-exponential in ψ as a transition matrix from the first split decomposition to a decomposition of V which we interpret as a kind of half-way point. This half-way point turns out to be the eigenspace decomposition of $\mathcal{M}$. We will discuss the eigenspace decomposition of $\mathcal{M}$ and give the actions of various operators on this decomposition.

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An iterative algorithm to compute the pseudospectral abscissa for real perturbations of a nonlinear eigenvalue problem

Linear dynamical systems of ordinary differential equations or delay differential equations generate, in the frequency domain, nonlinear eigenvalue problems that can be expressed by means of the same following general definition

$$\left(\sum_{i=1}^{m} A_i p_i(\lambda)\right) v = 0, \tag{1}$$

with matrices $\{A_i\}_{i=1}^m \in \mathbb{C}^{n\times n}$ and $\{p_i(\lambda)\}_{i=1}^m$ entire functions. If the spectral abscissa of the eigenvalue problem, i.e. the real part of the rightmost point of the spectrum, lies in the left half of the complex plane, then the stability of the system is guaranteed. Characterizing a class of ε-bounded perturbations of the coefficient matrices $\{A_i\}_{i=1}^m$ of the problem, we can define its pseudospectrum as the union set of the spectra of the problem perturbed under each set of perturbations $\{\delta A_i\}_{i=1}^m$ in the class. The pseudospectral abscissa, i.e. the real part of the rightmost point in the pseudospectrum, is a powerful tool to investigate the robustness of stability of the original problem and its distance to instability. In literature, algorithms computing the pseudospectral abscissa generated by unstructured complex-valued ε-perturbations already exist. However, from a practical point of view, real valued perturbations are more realistic; thus, analysing the ε-pseudospectrum arised from complex-valued perturbations may bring to misleading conclusions about the robustness of the problem. First, we hereby present a new iterative algorithm to compute the pseudospectral abscissa of a nonlinear eigenvalue problem perturbed by real-valued matrix perturbations $\{\delta A_i\}_{i=1}^m$. We implement two different methods that account for unstructured and structured perturbations on the coefficient matrices. In both cases, it is proved that the pseudospectral abscissa can be generated by a set of at most rank-2 optimal perturbations of $\{A_i\}_{i=1}^m$. Our iterative method starts from the eigenvalues located in the right part of the original spectrum, and by generating at each iteration new perturbed problems with increasing spectral abscissa, converges to the rightmost point of the pseudospectrum. Next, we show how effective is this method in the applications envisaged in control theory: the pseudospectral abscissa function is almost everywhere smooth w.r.t. the system parameters. By providing the function value and, wherever it exists, its first derivative, our method represents the main ingredient in the optimization of the pseudospectral abscissa of dynamical systems with control w.r.t. control parameters. As a consequence it represents an efficient tool in the stabilization of control systems and in the quantification of the distance to instability.

This is a joint work with Wim Michiels (Department of Computer Science, KU Leuven, Celestijnenlaan 200A, 3001, Heverlee, Belgium, *wim.michiels@cs.kuleuven.be*) and Nicola Guglielmi (Dipartimento di Ingegneria, Scienze Informatiche e Matematica and Gran Sasso Science Institute, Universit dell'Aquila, via Vetoio (Coppito), L'Aquila, Italy, *guglielm@univaq.it*)

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Semidefinite Programs with a Dash of Smoothness: Why and When the Low-Rank Approach Works

Semidefinite programs (SDPs) can be solved in polynomial time by interior point methods, but scalability can be an issue. To address this shortcoming, over a decade ago, Burer and Monteiro proposed to solve SDPs with few equality constraints via low-rank, non-convex surrogates. Remarkably, for some applications, local optimization methods seem to converge to global optima of these non-convex surrogates reliably.

In this presentation, we show that the Burer-Monteiro formulation of SDPs in a certain class almost never has any spurious local optima, that is: the non-convexity of the low-rank formulation is benign (even saddles are strict). This class of SDPs covers applications such as max-cut, community detection in the stochastic block model, robust PCA, phase retrieval and synchronization of rotations.

The crucial assumption we make is that the low-rank problem lives on a manifold. Then, theory and algorithms from optimization on manifolds can be used.

Select parts are joint work with P.-A. Absil, A. Bandeira, C. Cartis and V. Voroninski.

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Zero forcing and power domination

Zero forcing on a simple graph is an iterative coloring procedure that starts by initially coloring vertices white and blue and then repeatedly applies the following color change rule: if any vertex colored blue has exactly one white neighbor, then that neighbor is changed from white to blue. Any initial set of blue vertices that can color the entire graph blue is called a zero forcing set. The zero forcing number is the cardinality of a minimum zero forcing set. A well known result is that the zero forcing number of a simple graph is an upper bound for the maximum nullity of the graph (the largest possible nullity over all symmetric real matrices whose ijth entry (for $i \neq j$) is nonzero whenever $\{i, j\}$ is an edge in G and is zero otherwise). A variant of zero forcing, known as power domination (motivated by the monitoring of the electric power grid system), uses the power color change rule that starts by initially coloring vertices white and blue and then applies the following rules: 1) In step 1, for any white vertex w that has a blue neighbor, change the color of w from white to blue. 2) For the remaining steps, apply the color change rule. Any initial set of blue vertices that can color the entire graph blue using the power color change rule is called a power dominating set. We present results on the power domination problem of a graph by considering the power dominating sets of minimum cardinality and the amount of steps necessary to color the entire graph blue.

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Minimising the largest mean first passage time of a Markov chain and the influence of directed graphs

For a Markov chain described by an irreducible stochastic matrix A of order n, the mean first passage time $m_{i,j}$ measures the expected time for the Markov chain to reach state j given that the system begins in state i, thus quantifying the short-term behaviour of the chain. In this talk, we give a lower bound for the maximum mean first passage time in terms of the stationary distribution vector of A. We also discuss the characterisation of the directed graphs D for which any stochastic matrix A respecting this directed graph attains equality in the lower bound, thus producing a class of Markov chains with optimal short-term behaviour.

This is joint work with Steve Kirkland. This work was supported in part by NSERC grant no. RGPIN-2014-06123 and by the University of Manitoba Graduate Fellowship.

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Connected zero forcing

This talk considers a variant of zero forcing in which the initially colored set of vertices induces a connected subgraph. A related parameter of interest is the connected forcing number - the cardinality of the smallest initially colored connected vertex set which forces the entire graph to be colored. We discuss the complexity and different strategies for computing this parameter, derive closed formulas for it in specific families of graphs, present structural results about minimum connected forcing sets, and characterize graphs with extremal connected forcing numbers.

This work was supported by NSF Grant 1450681.

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The Permutation and Alternating Sign Matrix Rational Cones

This talk is based on some aspects of the recently published paper “Alternating Sign Matrices, extensions and related cones” by R.A. Brualdi and G. Dahl (*Advances in Applied Math.*, 86 (2017), 19–49). After a brief introduction to alternating sign matrices, we discuss and compare the cone generated by the set $\mathcal{P}_n$ of $n \times n$ permutation matrices and the cone generated by the set $\mathcal{A}_n$ of $n \times n$ alternating sign matrices.

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Nonintersecting Brownian motions on the unit circle with drift

Recently, Dong and Liechty determined the large-n asymptotic behavior of n Brownian walkers on the unit circle with non-crossing paths conditioned to start from the same point at time zero and end at the same point at a fixed ending time. We analyze the analogous problem with a nonzero drift. We obtain probabilities for winding numbers both for n fixed and in the $n \to \infty$ limit. We also derive a generalization of the tacnode process in a certain double-scaling limit. Our results follow from analysis of a Hankel determinant formula and related discrete orthogonal polynomials which are analyzed asymptotically via the nonlinear steepest-descent method for Riemann-Hilbert problems. This is joint work with Karl Liechty.

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A unified approach to Fiedler-like pencils via strong block minimal bases pencils.

The standard way of solving the polynomial eigenvalue problem associated with a matrix polynomial is to embed the matrix polynomial into a matrix pencil, transforming the problem into an equivalent generalized eigenvalue problem. Such pencils are known as linearizations. Many of the families of linearizations for matrix polynomials available in the literature are extensions of the so-called family of Fiedler pencils. These families are known as generalized Fiedler pencils, Fiedler pencils with repetition and generalized Fiedler pencils with repetition, or Fiedler-like pencils for simplicity.

The goal of this work is to unify the Fiedler-like pencils approach with the more recent one based on strong block minimal bases pencils. To this end, we introduce a family of pencils that we have named extended block Kronecker pencils, whose members are, under some generic nonsingularity conditions, strong block minimal bases pencils, and show that, with the exception of the non proper generalized Fiedler pencils, all Fiedler-like pencils belong to this family modulo permutations. As a consequence of this result, we obtain a much simpler theory for Fiedler-like pencils than the one available so far. Moreover, we expect this unification to allow for further developments in the theory of Fiedler-like pencils such as global or local backward error analyses and eigenvalue conditioning analyses of polynomial eigenvalue problems solved via Fiedler-like linearizations.

STEVE BUTLER
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The Z_q variation of zero forcing

Zero forcing is well known to bound the nullity of any matrix associated with a graph. One might want to further restrict the class of matrices to consider and see if zero forcing could not be improved for that class. One natural candidate is the class of matrices with at most q negative eigenvalues, and for this we examine Z_q which adds an extra option of zero forcing to get an improved bound on the nullity.

The Z_q *game* will be discussed, the bounds will be given, and more recent work on the properties of this parameter will also be covered.

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Truncated Toeplitz operators and their spectra

Truncated Toeplitz operators are a natural generalisation of finite Toeplitz matrices. We study properties of these operators such as invertibility and Fredholmness and we characterise their spectra, for symbols in certain classes, using the fact that truncated Toeplitz operators are equivalent after extension to 2×2 matricial Toeplitz operators.

This talk is based on joint work with Jonathan R. Partington

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The Gau-Wu number for 4×4 matrices.

For a given $n \times n$ matrix A, the Gau-Wu number, $k(A)$, is the maximal number of orthonormal vectors x_j such that the scalar products $\langle Ax_j, x_j \rangle$ lie on the boundary of the numerical range $W(A)$. Refining Chien and Nakazato's classification of 4×4 numerical ranges based on the singular points of the boundary generating curve, we give examples of matrices with different values of $k(A)$, sometimes subdividing the cases. We characterize matrices for which $k(A) = 4$ and give some preliminary results on the distinction between matrices for which $k(A)$ is 2 or 3.

This is joint work with P.X. Rault, T. Sendova, and I.M. Spitkovsky.

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On the implicit restart of the rational Krylov method

Krylov subspace methods are frequently used throughout scientific computing. In this talk we focus on the rational Krylov method which is used, among others, for the (non)linear eigenvalue problem, rational approximation, and contour integration.

Implicit restarting is often necessary and relies on applying QR steps on the recurrence matrices. Classically this is done by the explicit QR algorithm, not exploiting any structure of the recurrence matrices involved. Though theoretically fine, these explicit steps are costly and can exhibit numerical difficulties.

We will present a new approach using an implicit, structure preserving QR algorithm to overcome the classical drawbacks. To achieve this we apply an initial unitary transformation on the rational Krylov pencil that acts directly on a QR factored form of the recurrence matrices. This transformation allows for the application of a generalized implicit QZ step on the rational Krylov pencil that naturally preserves the structure in the recurrence matrices.

This proves to be an efficient framework for the formulation of the implicit restart of the rational Krylov method or, equivalently, for the application of a rational filter. It has multiple advantages over traditional approaches: complex conjugate Ritz pairs can be removed from real pencils in real arithmetic, the structure is preserved throughout the algorithm such that the subspace can be easily expanded after the contraction phase, and deflation of Ritz values can be carefully monitored.

We illustrate the viability of the new algorithm with some numerical examples

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Lexicographic polynomials of graphs and their spectra

For a (simple) graph H and non-negative integers $c_0, c_1, \ldots, c_d$ ($c_d \neq 0$), $p(H) = \sum_{k=0}^{d} c_k \cdot H^k$ is the lexicographic polynomial in H of degree d, where the sum of two graphs is their join and $c_k \cdot H^k$ is the join of c_k copies of H^k. The kth power of H with respect to the lexicographic product is denoted H^k ($H^0 = K_1$). The spectrum (if H is regular) and the Laplacian spectrum (in general case) of $p(H)$ are determined in terms of the spectrum of H and c_k's. Constructions of infinite families of cospectral or integral graphs are also presented.

This is joint work with P. Carvalho, P. Rama, S.K. Simic and Z. Stanic. This work was supported by Portuguese Foundation for Science and Technology - FCT, through the CIDMA - Center for Research and Development in Mathematics and Applications, within project UID/MAT/ 04106/2013.

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Throttling for Variants of Zero Forcing

The *color change rule* for zero forcing in a graph G is that a blue vertex v can force a white vertex w to become blue if and only if w is the only white neighbor of v in G. If B_0 is the initial set of blue vertices, let B_{i+1} be the set of blue vertices in G after the color change rule is applied to every vertex in the set B_i. Such a set B_0 is a *zero forcing set* in G if there exists a n such that $B_n = V(G)$. The *zero forcing number of* G is the size of a minimum zero forcing set. The *propogation time* for a zero forcing set B_0, $pt(G, B_0)$, is the smallest n such that $B_n = V(G)$. The *throttling number* of G for zero forcing is the minimum of $|B_0| + pt(G, B_0)$ where B_0 ranges over all zero forcing sets of G. Throttling for zero forcing has been studied by Butler and Young, *Australasian Journal of Combinatorics*, 2013. There are many variants of zero forcing that alter the color change rule. This talk will present results on throttling for some of these variants of zero forcing.

This is joint work with J. Kritschgau, K. Lorenzen, M. Ross, S. Selken, and V. Valle-Martinez.

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Matrix Tree Theorem for Schrödinger operators on networks

This work aims to interpret a family of distances in networks associated with effective resistances with respect to a parameter and a weight in terms of rooted spanning trees. Specifically, we consider the effective resistance distance with respect to a positive parameter and a weight; that is, effective resistance distance associated with an irreducible and symmetric M–matrix. This concept was introduced by the authors in relation with the full extension of Fiedler's characterization of symmetric and diagonal dominant M-matrices as resistive inverses to the case of symmetric M-matrices. The main idea is consider the network embedded in a host network with new edges that reflects the influence of the parameter. Then, we used the all minor tree Theorem to give an expression for the effective resistances in terms of rooted spanning forest.

This is joint work with A.M. Encinas and M. Mitjana

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Matrix population models: Connecting individuals and populations

The dynamics of populations depend on the survival, fertility, development, and movement of individuals. Individuals differ in those processes depending on their age, size, developmental stage, health status, physiological condition, past history, or a host of other variables. Formulating these dynamics as matrix operators has provided a rich framework for theoretical and applied population ecology. Indeed, the Perron-Frobenius theorem may have been invoked more frequently than any other mathematical result in conservation biology.

This talk will survey some recent developments that have opened new perspectives on the connection of individuals and populations, and that may be of interest to fans of linear algebra. These developments have inspired a tighter link between matrix population models and absorbing Markov chains, including Markov chains with rewards. As models for individual development, the results include the moments of lifetime reproductive output, lifetime income, and lifetime experience of health outcomes. One of the conclusions is an increased appreciation for the importance of individual stochasticity and unobserved heterogeneity as sources of variance in demographic outcomes.

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Thinning and conditioning of the Circular Unitary Ensemble

We apply the operation of random independent thinning on the eigenvalues of $n \times n$ Haar distributed unitary random matrices. We study gap probabilities for the thinned eigenvalues, and we study the statistics of the eigenvalues of random unitary matrices which are conditioned such that there are no thinned eigenvalues on a given arc of the unit circle. Various probabilistic quantities can be expressed in terms of Toeplitz determinants and orthogonal polynomials on the unit circle, and we use these expressions and Riemann-Hilbert techniques to obtain asymptotics as $n \to \infty$.

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Inequalities regarding group invertible H matrices

A result of Ostrowski states that for an invertible H matrix A, $|A^{-1}| \leq M(A)^{-1}$, where $M(A)$ is the comparison matrix of A. We will show for a real, group invertible, generalized diagonally dominant matrix (A GDD matrix is an H matrix), $A^{\#} \leq M(A)^{\#}$ under some conditions. We will prove some other inequalities regarding a group invertible H matrix and its' comparison matrix using a special splitting which gives a better bound for $A^{\#}$.

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Quantum algorithm for multivariate polynomial interpolation

How many quantum queries are required to determine the coefficients of a degree-d polynomial in n variables? We present and analyze quantum algorithms for this multivariate polynomial interpolation problem over the fields $\mathbb{F}_q$, $\mathbb{R}$, and $\mathbb{C}$. We show that $k_{\mathbb{C}}$ and $2k_{\mathbb{C}}$ queries suffice to achieve probability 1 for $\mathbb{C}$ and $\mathbb{R}$, respectively, where $k_{\mathbb{C}} = \lceil \frac{1}{n+1}\binom{n+d}{d} \rceil$ except for $d = 2$ and four other special cases. For $\mathbb{F}_q$, we show that $\lceil \frac{d}{n+d}\binom{n+d}{d} \rceil$ queries suffice to achieve probability approaching 1 for large field order q. The classical query complexity of this problem is $\binom{n+d}{d}$, so our result provides a speedup by a factor of $n+1$, $\frac{n+1}{2}$, and $\frac{n+d}{d}$ for $\mathbb{C}$, $\mathbb{R}$, and $\mathbb{F}_q$, respectively. Thus we find a much larger gap between classical and quantum algorithms than the univariate case, where the speedup is by a factor of 2. For the case of $\mathbb{F}_q$, we conjecture that $2k_{\mathbb{C}}$ queries also suffice to achieve probability approaching 1 for large field order q, although we leave this as an open problem.

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The Projected Power Method: A Nonconvex Algorithm for Joint Alignment

Various applications involve assigning discrete label values to a collection of objects based on some pairwise noisy data. Due to the discrete–and hence nonconvex–structure of the problem, computing the optimal assignment (e.g. maximum likelihood assignment) becomes intractable at first sight. This work makes progress towards efficient computation by focusing on a concrete joint alignment problem–that is, the problem of recovering n discrete variables given noisy observations of their modulo differences. Rather than solving it using low-rank matrix completion approaches, we propose a low-complexity and model-free procedure, which operates in a lifted space by representing distinct label values in orthogonal directions, and which attempts to optimize quadratic functions over hypercubes. We prove that for a broad class of statistical models, the proposed projected power method makes no error–and hence converges to the maximum likelihood estimate–in a suitable regime. We expect this algorithmic framework to be effective for a broad range of discrete assignment problems.

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Provably robust and fast low-rank matrix recovery with outliers

Low-rank matrix recovery is of central importance to many applications such as collaborative filtering, sensor localization, and phase retrieval. Convex relaxation via nuclear norm minimization is a powerful method, but suffers from computational complexity when the problem dimension is high. Recently, it has been demonstrated that gradient descent works provably for low-rank matrix recovery if initialized using the spectral method, therefore achieving both computational and statistical efficacy. However, this approach fails in the presence of arbitrary, possibly adversarial, outliers in the measurements. In this talk, we will describe how to modify the gradient descent approach via a median-guided truncation strategy, and show this yields provably recovery guarantees for low-rank matrix recovery at a linear convergence rate. While median has been well-known in the robust statistics literature, its utility in high-dimensional signal estimation is novel. In particular, robust phase retrieval and matrix sensing will be highlighted as special cases. This is based on joint work with Huishuai Zhang, Yuanxin Li, and Yingbin Liang.

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Approximation by partial isometries and symmetric approximation of finite frames

Let $\mathcal{M}_{m,n}$ be the space of complex $m \times n$ matrices, and let $\mathcal{I}_{m,n}^k$ be the set of $m \times n$ partial isometries of rank k. Given $F \in \mathcal{M}_{m,n}$, we find partial isometries $U \in \mathcal{I}_{m,n}^k$ such that

$$\|F - U\| = \min_{X \in \mathcal{I}_{m,n}^k} \|F - X\|,$$

where $\| \; \|$ is any unitarily invariant norm. When the norm is strictly convex, we give a characterization of all the minimizers.

As an application, we extend the notion of symmetric approximation of frames introduced in M. Frank, V. Paulsen, T. Tiballi, *Symmetric Approximation of frames and bases in Hilbert Spaces*, Trans. Amer. Math. Soc. 354 (2002), 777-793.

This is joint work with Jorge Antezana. This work was partially supported by PIP 0525 CONICET.

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Some assorted inequalities for positive linear maps

I looked into this topic since early 1970's. Now , I would re-examine some known results, so as to seek the new meanings of old values as well as to realize the new values of old meanings.

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Positive maps from mutually unbiased bases

We provide a class of linear positive maps in matrix algebras constructed in terms of Mutually Unbiased Bases (MUBs). Two orthonormal basis e_j and f_j in $\mathbb{C}^d$ are mutually unbiased if $|(e_i, f_j)|^2 = 1/d$ for any $i, j = 1, ..., d$. MUBs play significant role in quantum physics due to the fact that they encode complementary properties of a quantum system. Positive maps play an important role both in physics and mathematics providing generalizations of $*$-homomorphism, Jordan homomorphism and conditional expectation. Normalized positive maps define affine mappings between sets of states of C^*-algebras. Moreover, they provide a basic tool to analyze quantum entangled states. Interestingly, our class contains many well known examples of positive maps like e.g. celebrated Choi map. It is shown that positive maps constructed in terms of MUBs might be non-decomposable and hence may be used to detect so called bound entanglement. Moreover, some families of maps turned out to be optimal and extremal.

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Projection Methods for Riccati Equations

We consider the numerical solution of large-scale algebraic, differential and rational Riccati equations by projection methods, arising in the LQG optimal control of linear time-invariant (stochastic) systems with finite and infinite time-horizons. We first show the solutions are numerically low-rank thus projections methods are applicable. We then propose some appropriate Krylov subspaces derived from existing algorithms. More importantly, we prove that the solvability of the Riccati equations is inheritted by the projected equations, under mild and reasonable conditions. Note that the standard practice is to assume the solvability of the projected equations. Illustrative numerical examples are presented.

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Maximizing the order of a regular graph with given valency and second eigenvalue

From the work of Alon and Boppana, and Serre, we know that given $k \geq 3$ and $\theta < 2\sqrt{k-1}$, there are finitely many k-regular graphs whose second largest eigenvalue of the adjacency matrix is at most θ. In this talk, we will discuss the largest order of such graphs. This is joint work with Jack Koolen, Hiroshi Nozaki and Jason Vermette.

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The Gelfand-Zeitlin integrable system for complex orthogonal Lie algebras

Kostant and Wallach introduced the Gelfand-Zeitlin (GZ) integrable system on $\mathfrak{gl}(n, \mathbb{C})$ and studied the Lagrangian flows and generic fibres of the moment map of the system. In this talk, we discuss the analogous integrable system on $\mathfrak{g} = \mathfrak{so}(n, \mathbb{C})$. We study the geometry of this integrable system by studying the adjoint action of the symmetric subgroup $K = SO(n-1, \mathbb{C})$ on $\mathfrak{g}$. We use the theory of K-orbits on the flag variety of $\mathfrak{g}$ to describe the nilfibre of the geometric invariant theory quotient $\mathfrak{g} \to \mathfrak{g}//K$. Using our description of the nilfibre and the Luna slice theorem, we develop an analogue of the classical Jordan decomposition for the K-action on $\mathfrak{g}$ and use it to describe the points in the moment fibres of the GZ integrable system where the flows are Lagrangian. If time permits, we will briefly discuss our approach to understanding the geometry of the moment fibres at singular points of the integrable system using the theory of flat deformations of schemes. This is joint work with Sam Evens.

SAM COLE

A simple algorithm for spectral clustering of random graphs

A basic problem in data science is to partition a data set into 'clusters' of similar data. When the data are represented in a matrix, the spectrum of the matrix can be used to capture this similarity. This talk will consider how this spectral clustering performs on random matrices. Specifically, we consider the planted partition model, in which $n = ks$ vertices of a random graph are partitioned into k clusters, each of size s. Edges between vertices in the same cluster and different clusters are included with constant probability p and q, respectively (where $0 \leq q < p \leq 1$). We present a simple, efficient algorithm that, with high probability, recovers the clustering as long as the cluster sizes are are least $\Omega(\sqrt{n})$.

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Quantum walks on trees

A graph can very conveniently model a system of interacting quantum particles. When this system evolves, we observe a quantum walk, and this is completely described by the spectral information of the graph. The connection between graph theory, linear algebra and quantum physics has been observed and studied for quite some time now, but still many questions remain open. In this talk, I will focus on what we know, including some recent results, and what we want to discover about quantum walks on trees. No prior knowledge of physics will be needed.

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Some Matrix Population Models with Imprimitive Projection Matrices

A matrix model for the dynamics of a structured population involves a projection matrix P that maps, by multiplication, a demographic state vector x from one census time to the next. The projection matrix P is typically non-negative and irreducible. If P = P(x) depend on the demographic vector, then the resulting (discrete time) dynamical system defined by the map P(x)x is nonlinear. The extinction or survival of a population is, of course, a fundamental biological question. In terms of the matrix model, this question involves the stability or instability of the extinction equilibrium x = 0. If P(0) is primitive, the bifurcation that results from the destabilization of the extinction equilibrium, as a model parameter changes, are those of a classic transcritical bifurcation: a branch of positive equilibria is created by the bifurcation and the stability of the bifurcating positive equilibria depends on the direction of bifurcation. Applications arise, however, in which P(0) is imprimitive. In this case, the bifurcation that occurs upon destabilization of the extinction equilibrium is more complicated and not thoroughly understood in general. I will discuss this bifurcation for imprimitive matrix models that arise from some selected applications.

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Laplacian Energy, threshold graphs and majorization

The notion of majorization plays an important role in matrix theory and combinatorics. This talk discusses majorization in connection with some spectral graph theory type of questions for the class of threshold graphs. The Laplacian energy of a graph measures how the eigenvalues of its Laplacian matrix deviate from the average degree. We show how to maximize or minimize the Laplacian energy of threshold graphs, using majorization techniques for integer partitions. Moreover, we use similar ideas to maximize or minimize the Laplacian spread within this class of graphs.

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A Geometric Framework For Density Modeling

We study a classical problem in statistics – estimation of probability density functions (pdfs) — using tools from manifold optimization. The basic idea is to obtain an initial guess of the density using any current and efficient technique. Then, we transform this guess into a final estimate using a transitive action of the diffeomorphism group. This transformation is solved for as an optimization problem under the log-likelihood of given data. One advantage of this action is that the resulting function is already a pdf, and does not require any further normalization. The drawback is of course that the diffeomorphism group is not linear space, and one need to solve a manifold optimization problem. We use a mapping from the diffeomorphism group to a finite-dimensional subspace of the Lie algebra, and transfer the optimization problem on to that linear subspace. Elements of this subspace are represented using finite number of coefficients with respect to a chosen basis. We solve this optimization using constraint optimization function in Matlab. This framework is introduced for univariate, unconditional pdf estimation and then extended to conditional pdf estimation. The approach avoids many of the computational pitfalls associated with current methods without losing on estimation performance. In presence of irrelevant predictors, the approach achieves both statistical and computational efficiency compared to classical approaches for conditional density estimation. We derive asymptotic convergence rates of the density estimator and demonstrate this approach using synthetic datasets, and a case study to understand association of a toxic metabolite on preterm birth.

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The effects of different types of density dependence in the evolution of partial migration

Partial migration -the coexistence of migrant and non-migrant phenotypes- is widespread among animals, but the evolutionary basis of this phenomenon remains poorly understood. We use a nonlinear Leslie matrix model to compare four forms of commonly occurring density dependence during reproduction, and determine when they allow for partial migration as an evolutionary stable strategy (ESS) and convergent stable strategy (CSS) in the adaptive dynamics framework.

Only three of the four forms of density dependence possibly allow the evolution of partial migration. Most notably, this happens when migrants and non-migrants breed in isolation and only experience density dependence within their phenotype. In contrast, when both phenotypes breed in a common habitat, density dependence depends on the sum of the abundances of both phenotypes for each type, and partial migration cannot evolve. Finally, when one phenotype experiences density dependence only within its type, but the other experiences the sum of both phenotypes, then partial migration may evolve under certain conditions which are characterized analytically via our model.

These results shed new light on the role of density dependence in the evolution of partial migration and are relevant for a diverse set of taxa.

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Graphs with all but two eigenvalues in $[-2, 0]$

Let G be a graph on n vertices and write A for the adjacency matrix of G. The eigenvalues of a graph are those of its adjacency matrix. Recently, Cioaba et al., in [1], characterized all graphs which have all but two eigenvalues equal to -2 and 0 and set whose are determined by their spectrum. In this talk, we present an extension of their result by explicitly determining the graphs with all but two eigenvalues in the interval $[-2, 0]$.

Reference

[1] S. Cioaba, W. Haemers and J. Vermette, The graphs with all but two eigenvalues 0 or -2, to be published in Designs, Codes and Cryptography (2017).

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Matroids and the minimum rank problem for zero-nonzero patterns

The *zero-nonzero pattern* of a matrix specifies precisely which of its entries are nonzero. Determining the minimum possible rank of a matrix subject to such a description is a problem that has received considerable attention. The main goal of this work is to generalize this problem to the setting of matroids. We show that a basic combinatorial lower bound on the minimum rank continues to hold in this generalized setting. The question of when this bound is actually met by a matrix is one we can then examine in terms of matroid representability. We can use this connection to explain some previously-known results, and to produce new examples. Ultimately, the potential of this approach seems largely untapped; we outline directions in which the connections with matroid theory could be strengthened so as to shed more light on the original matrix-theoretic problem.

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The Minc-type bound and the eigenvalue inclusion sets of the general product of tensors

In this paper, we give the Minc-type bound on spectral radius for nonnegative tensors. We also present some bounds on the spectral radius and the eigenvalue inclusion sets for the general product of tensors.

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Distribution-Free Consistency of Graph Clustering

The theory of dense graph limits shows how to embed arbitrary sized matrices of the form $M \in [0,1]^{m\times m}$ in a common graphon space consisting of symmetric measurable functions of the form $W : [0,1]^2 \to [0,1]$. The space of such functions is equipped with a norm called the cut-norm, which is canonical for dense matrices. In our paper, we prove the continuity of top eigenvectors of the Laplacian associated to such matrices with respect to the cut norm. As a consequence, we derive distribution-free consistency results for spectral clustering. In this talk, we will discuss the cut-norm, the novel framework we have developed for the analysis of graph clustering, and the technical results required to derive our results.

This is joint work with Apoorva Khare, Dominique Guillot, and Bala Rajaratnam.

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Generic matrix polynomials with fixed rank and fixed degree

We show that the set $m \times n$ complex matrix polynomials of grade d, i.e., of degree at most d, and rank at most r ($r = 1, \ldots, \min\{m, n\} - 1$) is the union of the closures of the $rd + 1$ sets of matrix polynomials with rank r, degree d, and explicitly described complete eigenstructures. These $rd + 1$ complete eigenstructures correspond to generic $m \times n$ matrix polynomials of grade d and rank at most r. The analogous problem is also considered for complex skew-symmetric matrix polynomials of odd grade. In this case, there is only one generic complete eigenstructure, which shows a drastic effect of imposing the structure on matrix polynomials.

This is a joint work with Froilán M. Dopico.

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Ideals of Lower Triangular Toeplitz Matrices

Toeplitz matrices, $T = [t_{ij}]$, where $t_{ij} = t_{j-i}$, arise in many areas such as network systems, and graph theoretic tasks.Studying the abstract structures of these matrices may prove to be useful in improving such applications.

Our recent work on the algebraic structures of Lower Triangular Toeplitz matrices revealed remarkable results on its ring properties, in particular on the structure of its ideals.In this presentation, we will primarily present the nature and the structure of the ideals. Among other properties, we will, for instance, discuss the unique structure of its principal ideas as well as the structure of its maximal ideal. We will also argue that the ring's ideals are all principal ideals.

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Multi-Faceted Nature of Matrices

Matrices take on different meanings in different domains within linear algebra. Yet, the learners are expected to recognize each meaning, and be flexible enough to make connections between the multiple ideas represented by the very same matrices. In fact, many students in the first year linear algebra courses, for the most part, are not able to cope with a single matrix representation of a wide range of ideas. We propose to present the nature of the first year linear algebra students' interaction with matrices, and their difficulties in coping with the multiple dimensional applications. We will furthermore support our presentation with snippets from classroom tasks.

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Paul Van Dooren's Index Sum Theorem and the solution of the inverse rational eigenvalue problem

A very young Paul Van Dooren proved in his PhD Thesis an index sum theorem for the poles, zeros, and minimal indices of any rational matrix. Much later, several authors proved index sum theorems for polynomial matrices without establishing any connection with the original result proved by Paul Van Dooren. In fact, the matrix polynomial index sum theorem was fundamental in the solution of the complete inverse eigenstructure problem for polynomial matrices provided in 2015 by De Teran, Dopico, and Van Dooren (SIMAX, 36 (2015)). In this talk we establish connections between rational and polynomial index sum theorems, showing that each of them implies the other, we extend Paul Van Dooren's Index Sum Theorem to arbitrary fields, and we prove that a list of zeros and poles, together with their corresponding partial multiplicities, and left and right minimal indices are the complete set of structural data of a rational matrix if and only if they satisfy Paul Van Dooren's Index Sum Theorem.

This is joint work with Luis M. Anguas (Universidad Carlos III de Madrid, Spain), Richard Hollister (Western Michigan University, USA), and D. Steven Mackey (Western Michigan University, USA). This work was supported by Ministerio de Economia, Industria y Competitividad of Spain and Fondo Europeo de Desarrollo Regional (FEDER) of EU through grants MTM-2015-68805-REDT, MTM-2015-65798-P (MINECO/FEDER, UE).

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Schwartz's Model of Business Cycles

We consider a structure E:=(C,M) consisting of a set C and a square matrix M:$C \times C \to R$. We say that such a structure is a Leontief economy if M is an irreducible non-negative matrix. In this situation the set C is called the set of 'commodities' of the economy and the matrix M is called the 'input-output' matrix of the economy. Recall that it follows that M has a positive eigenvalue γ and this eigenvalue has a corresponding positive eigenvector. The eigenvalue is called the 'Perron root' or 'dominant eigenvalue'. We shall write γ:=dom(M).

Note that a Leontief economy is a 'static' object. We want to consider dynamical objects. So we consider a structure D:=(X,F) consisting of a set X and a map $F : X \to X$. A (discrete) dynamical system is a pair (X,F) consisting of a set X, called the phase space of the system, together with a map $F : X \to X$, called the transition map of the system. We shall say that a subset Y of X is an invariant set of this system if the restriction of F to Y has range in Y. Then the pair (Y,F) is a subsystem of the system (X,F). Sometimes we can understand a dynamical system by studying its invariant subsystems.

Schwartz(1961) presents a number of dynamical systems as models of the U.S. economy. In this talk we shall review Schwartz's 'labor eliminated' economy. This economy $E := (C, \pi)$ has a input-output matrix with Perron root γ:=dom(π) that satisfies 0¡γ¡1. In particular, we shall see that this model has a invariant two-dimensional subsystem that has the following form. Here is a description of this system. We take

$$X := \{(a, b) \in R^2 : 0 \leq a, 0 \leq b \text{ and } \gamma a \leq b\}$$

to be the state space. We define the transition map F:Xfh??X by

$$F(a, b) := (\min([\bar{\gamma}a - b]^+, ((1 - \gamma)a + b)/\gamma), (1 - \gamma)a + b)$$

where the function $+ : R \to R$ is defined by $x \mapsto x+ := max(0, x)$. This system often has limit cycles. These limit cycles provide examples of 'business cycles'.

For information see http://orion.math.iastate.edu/driessel/15Models.html .

This joint work with Irvin Hentzel and James Murdock.

Reference: Schwartz, Jacob T. (1961,2014), Lectures on the Mathematical Method in Analytical Economics, Martino Publishing.

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The effective resistance of extended or contracted networks

The effective resistance on a given a network is a distance on it, intrinsically associated with the combinatorial Laplacian. This means that to compute the effective resistance, all vertices are equally considered and the only parameters really significant are the weight on each edge, its *conductance*. It results that this distance is very sensitive to small changes in the conductances and then allows us to discriminate between networks with similar structure.

It is possible to define effective resistances that, in addition to the conductance, also take into account a weight on each vertex. These *generalized effective resistances* also determine distances on the network, one for each normalized weight on the vertex set, and coincide with the former one if the weight is constant; that is, when it does not discriminate between vertices. It is known that this family of distances are associated with linear operators on the network, more general that the combinatorial Laplacian, namely positive semidefinite Schödinger operators.

The aim of this communication is to analyze the behavior of these distances under the usual network transformations, specially the so-called *Star-Mesh* transformation. We also compute the effective resistance for an *extended network*; that is the network obtained from the former one by joining a new vertex, and then study the effect of the *contraction of this new network*; that is we apply a star-mesh transformation with center in the joined vertex.

This is joint work with A. Carmona and M. Mitjana. This work was supported by Spanish Research Council under project MTM2014-60450-R.

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On the Diagonal Stability of Metzler Matrices

In this talk we will review diagonal stability of Metzler matrices.

Shorten and Narendra [1, 2] have described the diagonal stability of a Metzler matrix by the conditions of the existence of a common diagonal Lyapunov function for two lower dimensional matrices. We will first address the alternative proof of this expression. We will then also derive novel extensions of the result based on Kalman-Yacubovich-Popov lemma [3].

[1] K.S. Narendra, R.N. Shorten, Hurwitz Stability of Metzler Matrices, IEEE Transactions Automatic Control, vol. 55, no. 6, pp. 1484-1487, 2010.

[2] R.N. Shorten and K.S. Narendra, On a theorem of Redheffer concerning diagonal stability, Linear Algebra and its Applications, vol. 431, no. 12, pp. 2317-2329, 2009.

[3] A. Rantzer, On the Kalman-Yacubovich-Popov Lemma for Positive Systems, IEEE Transactions Automatic Control, vol. 61, no. 5, pp. 1346-1349, 2016.

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Hadamard Powers, Critical Exponents, and Total Positivity

An $m \times n$ matrix A is called totally nonnegative, TN (resp. totally positive, TP) of every minor of A is nonnegative (resp. positive). For an entry-wise nonnegative matrix $B = [b_{ij}]$ and $t > 0$, $B^{\circ t}$ is defined to be the matrix with entries b_{ij}^t (tth Hadamard power of B). It is known that $A^{\circ t}$ need not be TN nor TP whenever A is TN or TP. However, if A is TP, then $A^{\circ t}$ is eventually TP.

On the other hand, if B is a $n \times n$ positive semidefinite and entry-wise nonnegative matrix, then $B^{\circ t}$ is positive semidefinite for all $t \geq n-2$. The number $n-2$ is referred to as a Hadamard critical exponent. In this talk we will show that for $n \geq 5$, there is no Hadamard critical exponent in the TP setting. We will also explore similarities between the positive semidefinite case and the class of TP Hankel matrices.

This work is joint with Profs. A. Sokal and C.R. Johnson

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Isometries and contractions of density operators relative to the Bures metric

The Bures metric is a metric on the set of all density matrices. The definition of the metric is based on the fidelity of pairs of density matrices; as such, the definitions of density matrix and Bures metric may be extended to any positive element and to pairs of positive elements in a unital C*-algebra that possesses a faithful trace functional. In this lecture, I will discuss joint work with Mizanur Rahaman on the structure of trace-preserving positive linear maps on unital tracial C*-algebras that induce isometries and contractions on the metric space of density elements.

MARC FELDMAN

Reduction Principle for recombination, mutation and migration

Early population genetic models for the evolution of recombination, mutation and migration showed that, for a number of special cases, these evolutionary forces should become weaker. This 'Reduction Principle' was proved using Perron-Frobenius theory for the eigenvalues of positive matrices. We have recently generalized these results greatly. Using theorems proved by Karlin, concerning the spectral radius of a matrix function, which he developed for an entirely different purpose, we have shown that the Reduction Principle for recombination, mutation and migration is a consequence of a common eigen- structure of local stability matrices that, at first glance, do not appear to share mathematical properties.

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Power domination and zero forcing in interated line digraphs

We present lower and upper bounds for the zero forcing number of digraphs obtained by the application of the line digraph operator over an arbitrary digraph. We prove that both bounds give the zero forcing number of iterated line digraphs of regular digraphs.

We also provide a relationship between the zero forcing number and the power domination number of a digraph; in the case of iterated line digraphs, such relationship permits to obtain one from the other. As a consequence we obtain the power domination number of iterated line digraphs of regular digraphs.

We conclude by comparing our results for zero forcing with previous results for the maximum nullity of iterated line digraphs.

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A Note on Structured Pseudospectra of Block Matrices

In this note we consider the question of equivalence of pseudospectra and structured pseudospectra of block matrices. The structures we study are all so called double structures; that is, the blocks of the given matrix are of the same structure as the block matrix. The approach is based on that of non-block matrices, which are also briefly studied, and the use of distance to singularity. We also list some open problems and conjectures.

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The core variety and representing measures in multivariable moment problems

Let $\beta \equiv \beta^{(m)} = \{\beta_i\}_{i \in \mathbb{Z}_+^n, |i| \le m}$, $\beta_0 > 0$, denote an n-dimensional real multisequence of degree m. The Truncated Moment problem concerns the existence of a positive Borel measure μ, supported in $\mathbb{R}^n$, such that $\beta_i = \int_{\mathbb{R}^n} x^i d\mu$ $(i \in \mathbb{Z}_+^n, |i| \le m)$.We associate to β an affine variety in $\mathbb{R}^n$ called the *core variety*, $\mathcal{V} \equiv \mathcal{V}(\beta)$. We prove that β has a representing measure μ (as above) if and only if the core variety is nonempty, in which case there exists a finitely atomic representing measure ν, supported in $\mathcal{V}$, such that $card\ supp\ \nu \le dim\ \mathbb{R}[x]_m$ $-dim\{p \in \mathbb{R}[x]_m : p|\mathcal{V} \equiv 0\}$. An analogous result also holds in the Full Moment Problem for $\beta^{(\infty)}$.

This is joint work with Grigoriy Blekherman.

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Multiplying Matrices: an activity based approach.

with Edgar Possani and María Trigueros

In this talk we will present an analysis of the results of the use of a set activities we have designed to teach matrix multiplication and its links with matrix functions. The analysis,uses APOS Theory as theoretical framework and covers results obtained by three groups of students taking an introductory course in Linear Algebra. Students modeled a problem, dealing with pesticide consumption by plants and animals, which motivates and gives meaning to matrix multiplication. Additional activities were designed based on a genetic decomposition to help students to construct the link of matrix multiplication with functions. We later evaluate the effectiveness of this approach, and explain the main difficulties encountered by students in terms of the theoretical framework.

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Nordhaus-Gaddum Bounds for Power Domination

Let $G = (V, E)$ be a simple graph (no loops or multiple edges) and let $\overline{G} = (V, \overline{E})$ be its complement. Given vertices $u, v \in V$, the edge $\{u, v\}$ is in $\overline{E}$ if and only if it is not in E. Given a graph parameter ρ, Nordhaus-Gaddum problems ask for a (tight) upper and lower bounds for $\rho(G) + \rho(\overline{G})$ or $\rho(G) \times \rho(\overline{G})$. Nordhaus and Gaddum gave tight bounds for the chromatic number, and many other graph parameters have been investigated. We extend this list to the power domination. Power domination is a coloring game played on a simple graph that comes from the electrical engineering challenge of efficiently monitoring an electric power grid. The game is a combination of a domination step followed by zero focing. The Nordhaus-Gaddum bounds for power domination illustrate that power domination behaves very differently from both domination and zero forcing.

This is joint work with K. F. Benson, D. Ferrero, V. Furst, L. Hogben and V. Vasilevska.

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Concave Mirsky Inequality and Low-Rank Recovery

We propose a simple proof of a generalized Mirsky inequality comparing the differences of singular values of two matrices with the singular values of their difference. We then discuss the implication of this generalized inequality for the recovery of low-rank matrices via concave minimization.

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Realizations of nonsymmetric hypergroups of rank 4 as association schemes

By considering only the relations of an association scheme and their products, one obtains a structure similar to that of a group, except that the product of two elements may be multivalued, and each element can be paired with another that behaves only partially like the inverse of the first. We call such a structure a hypergroup. One can then ask which hypergroups can be obtained from association schemes, and which of these can be obtained from finite association schemes. There are 37 nonsymmetric hypergroups of rank 4. In this talk, we discuss what we currently know about the existence of realizations of these hypergroups, and we present some of the techniques that we are using to try to extend this knowledge.

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Entanglement of Boson quantum states

An (m, n)-Boson quantum state is a symmetric tensor $\mathcal{B}$ in $\otimes^m \mathbb{C}^n$ of Hilbert-Schmidt norm one. Denote by $\|\mathcal{B}\|_\infty$ and $\|\mathcal{B}\|_1$ the spectral and nuclear norms of $\mathcal{B}$ respectively.

An entanglement of $\mathcal{B}$ can be measured by either $-2\log_2 \|\mathcal{B}\|_\infty$ or $2\log_2 \|\mathcal{B}\|_1$. First we show that the maximum entanglement of an (m, n)-Boson is bounded above by $\log_2 \binom{m+n-1}{m-1}$. Second we show that most of the Bosons are maximally entangled, i.e., their entanglement is close to the above upper bound. Third we show that the entanglement of $(m, 2)$ Bosons, (symmetric qubits), is polynomially computable.

Let $\mathcal{D}$ be a hermitian density tensor in $\otimes^m \mathbb{C}^{2n}$ corresponding to (m, n)-Boson states. The inseparability of $\mathcal{D}$ is measured by $\log_2 \|\mathcal{D}\|_1$. We show that the measure of inseparability of a real density tensor corresponding to $(m, 2)$ Bosons is polynomially computable.

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Zero forcing and power domination for tensor products of graphs

The power domination problem in graph theory arises from electrical companies' need to monitor the state of their networks continuously. This is achieved by the placement of so-called Phase Measurement Units at (the equivalent of) vertices in a power dominating set. The power domination number, the minimum cardinality of a power dominating set, is related to the zero forcing number, through the observation that a set S of vertices of a graph G is a power dominating set of G if and only if the closed neighborhood of S is a zero forcing set for G. In this talk, we will describe a new upper bound on the zero forcing number of the tensor product of an arbitrary graph G with a complete graph $K_n, n \geq 4$. In the case where G is a path or a cycle, this bound implies exact values for the zero forcing number, and the maximum nullity, of $G \times K_n$; consequently, we obtain new exact values for the power domination number of $G \times K_n$.

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A real-valued method for improving efficiency of a contour integral eigenvalue solver

In this talk, we present a method for improving the efficiency of a contour integral eigenvalue solver for real and symmetric generalized eigenvalue problems. Contour integral eigenvalue solvers have attracted much attention because of their high parallel efficiency. However, they require solving complex linear systems even if the target eigenvalue problem is real. Recently, we proposed a linear solver for complex symmetric linear systems that involves only real matrix and vector operations. To avoid the disadvantage of contour integral eigenvalue solvers, we combine them with the real-valued linear solver, and evaluate the performance using eigenvalue problems arising in several practical applications.

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Manifold Learning on Fibre Bundles

We develop a geometric framework, based on the classical theory of fibre bundles, to characterize the cohomological nature of a large class of synchronization-type problems in the context of graph inference and combinatorial optimization. In this type of problems, the pairwise interaction between adjacent vertices in the graph is of a 'non-scalar' nature, typically taking values in a group or groupoid; the 'consistency' among these non-scalar pairwise interactions provide information for the dataset from which the graph is constructed. We model these data as a fibre bundle equipped with a connection, and consider a horizontal diffusion process on the fibre bundle driven by a standard diffusion process on the base manifold of the fibre bundle; the spectral information of the horizontal diffusion decouples the base manifold structure from the observed non-scalar pairwise interactions. We demonstrate an application of this framework on evolutionary anthropology.

This is joint work with Ingrid Daubechies, Sayan Mukherjee, and Jacek Brodzki.

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Tree Sign Patterns that Require $\mathbb{H}_n$

A sign pattern (matrix) $\mathcal{A}$ is a matrix whose entries are from the set $\{+, -, 0\}$. The qualitative class of $\mathcal{A}$, denoted $Q(\mathcal{A})$, is defined as $Q(\mathcal{A}) = \{B \in M_n(\mathbb{R}) \mid \text{sgn}(B) = \mathcal{A}\}$. The refined inertia of a square real matrix B, denoted $\text{ri}(B)$, is the ordered 4-tuple $(n_+(B),\ n_-(B),\ n_z(B),\ 2n_p(B))$, where $n_+(B)$ (resp., $n_-(B)$) is the number of eigenvalues of B with positive (resp., negative) real part, $n_z(B)$ is the number of zero eigenvalues of B, and $2n_p(B)$ is the number of pure imaginary eigenvalues of B. For $n \geq 3$, the set of refined inertias $\mathbb{H}_n = \{(0, n, 0, 0), (0, n-2, 0, 2), (2, n-2, 0, 0)\}$ is important for the onset of Hopf bifurcation in dynamical systems. An $n \times n$ sign pattern $\mathcal{A}$ is said to require $\mathbb{H}_n$ if $\mathbb{H}_n = \{\text{ri}(B) | B \in Q(\mathcal{A})\}$. Bodine et al. conjectured that no $n \times n$ irreducible sign pattern that requires $\mathbb{H}_n$ exists for n sufficiently large, possibly $n \geq 8$. In this talk, we discuss the star and path sign patterns that require $\mathbb{H}_n$. It is shown that for each $n \geq 5$, a star sign pattern requires $\mathbb{H}_n$ if and only if it is equivalent to one of the five sign patterns identified in the talk. This resolves the above conjecture. It is also shown that no path sign pattern of order $n \geq 5$ requires $\mathbb{H}_n$.

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Combinatorial and Algebraic Conditions that preclude SAPpiness

It is well known that a complex zero-nonzero pattern cannot be spectrally arbitrary if its digraph doesn't have at least two loops and at least one two cycle, or at least three loops. This talk focuses on several other combinatorial conditions on the digraph that preclude it from being spectrally arbitrary. In particular we are sometimes able to reduce the number of unknown entries to be below the threshold of $2n - 1$. Furthermore there are several algebraic conditions on the coefficients of the characteristic polynomial that can be exploited to show that a pattern is not spectrally arbitrary over any field. Using Sage we were able to show that no zero-nonzero pattern with $2n - 1$ nonzero entries will be spectrally arbitrary over $\mathbb{C}$ where $n \leq 6$. When $n = 7$ we find two zero-nonzero patterns that do not satisfy our algebraic conditions precluding them from being spectrally arbitrary.

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The FEAST Eigenvalue Algorithm with Inexact Solves

The FEAST eigenvalue algorithm uses a contour integration-based rational function filter in order to rapidly solve for the eigenvectors whose eigenvalues are in some arbitrary, user-defined region in the complex plane. The traditional FEAST algorithm applies rational function filters by using sparse matrix factorization to solve linear systems, but it is sometimes inadvisable or impossible to factorize the matrix of interest. In these cases it is necessary to solve the FEAST linear systems iteratively by using Krylov subspace methods. We show that when FEAST is implemented by using Krylov linear system solvers, it is equivalent to a restarted Krylov eigenvalue algorithm. We discuss the implications of this for the behavior of FEAST, and offer some examples of situations where the resulting Iterative FEAST algorithm may have advantages over more traditional Krylov methods.

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Symmetry transformations on Grassmann spaces

In the past few years a serious attention was given to possible generalisations of the famous Wigner theorem on quantum mechanical symmetry transformations. We recall that Wigner's theorem states that every transformation on the projective space of all lines of a Hilbert space that leaves the angle invariant is implemented by a linear or conjugatelinear isometry of the underlying Hilbert space. Note that lines represent pure states of a quantum system, and the so-called transition probability between two pure states is simply the squared cosine of the angle between the representing lines.

Recently, several generalisations of Wigner's theorem have been found in the setting of Grassmann spaces, i.e. on spaces of certain kind of subspaces (e.g. of all n-dimensional subspaces). In my talk I will give an overview of these recent developments, will explain the main ideas behind the proof of one of my recent works, and if time permits, will pose some open problems as well.

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Geometric graphs and uniform embeddings

Many real-life networks can be modelled by stochastic processes with a spatial embedding. The spatial reality can be used to represent attributes of the vertices which are inaccessible or unknown, but which are assumed to inform link formation. For example, in a social network, vertices may be considered as members of a social space, where the coordinates represent the interests and background of the users. The graph formation is modelled as a stochastic process, where the probability of a link occurring between two vertices decreases as their metric distance increases. A fundamental question is to determine whether a given network is compatible with a spatial model. That is, given a graph how can we judge whether the graph is likely generated by a spatial model, and if so whether the model is uniform in nature?

Using the theory of graph limits, we show how to recognize graph sequences produced by random graph processes with a linear embedding (a natural embedding into real line). We then discuss whether a linear embedding is uniform in nature, that is whether it is possible to 'transform' the linear embedding into one in which the probability of a link between two vertices depends only on the distance between them. We give necessary and sufficient conditions for the existence of a uniform linear embedding for random graphs with finite number of probability values. Our findings show that for a general linear embedding the answer is negative in most cases.

This talk is based on joint articles with H. Chuangpishit, M. Hurshman, J. Janssen, and N. Kalyaniwalia.

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On the asymptotic analysis of Toeplitz + Hankel determinants.

We want to analyse the asymptotics of a Toeplitz+Hankel determinant with Toeplitz symbol $\phi(z)$ and Hankel symbol $w(z)$. When symbols $\phi(z)$ and $w(z)$ are related in specific ways, the asymptotics of T+H determinants have been studied by E. Basor and T. Ehrhardt and by P. Deift, A. Its and I. Krasovsky. The distinguishing feature of this work is that we do not assume any relations between the symbols $\phi(z)$ and $w(z)$. In this talk, the Hankel symbol is a modified Jacobi weight and the Toeplitz symbol is assumed to be analytic in a neighborhood of the unit circle. we approach this problem by analysing a 4 by 4 Riemann-Hilbert problem. This work is part of the joint research project with Alexander Its, Percy Deift and Igor Krasovsky.

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Spectrally Arbitrary Zero-Nonzero Patterns over Rings with Unity.

A zero-nonzero matrix pattern $\mathcal{A}$ is a square matrix with entries $\{0, *\}$. A $n \times n$ pattern $\mathcal{A}$ is spectrally arbitrary over a ring $\mathcal{R}$ if for each n-th degree monic polynomial $f(x) \in \mathcal{R}[x]$, there exist a matrix A over $\mathcal{R}$ with pattern $\mathcal{A}$ such that the characteristic polynomial $p_A(x) = f(x)$. A $n \times n$ pattern $\mathcal{A}$ is relaxed spectrally arbitrary over $\mathcal{R}$ if for each n-th degree monic polynomial $f(x) \in \mathcal{R}[x]$, there exist a matrix A over $\mathcal{R}$ with either pattern $\mathcal{A}$ or a subpattern of $\mathcal{A}$ such that the characteristic polynomial $p_A(x) = f(x)$. We consider whether a pattern $\mathcal{A}$ that is spectrally arbitrary over a ring $\mathcal{R}$ is spectrally arbitrary or relaxed spectrally arbitrary over another ring $\mathcal{S}$. In particular, we discovered that a pattern that is spectrally arbitrary over $\mathbb{Z}$ is relaxed spectrally arbitrary over $\mathbb{Z}_m$ for all m. We also determined the minimum number of $*$ entries to be spectrally arbitrary over $\mathbb{Z}$.

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Graph invariants from quantum walks

Work in quantum computing leads physicists to ask questions about matrices of the form $\exp(itM)$, where M is the adjacency (or Laplacian) matrix of a graph. Such a family of matrices defines what is known as a *continuous quantum walk*. Questions raised by physicists about these walks lead to a number of interesting mathematical problems; the basic goal is to derive properties of the associated quantum system from properties of the underlying graph. In my talk I will discuss some of these problems, but I will actually focus on some new graph invariants that have arisen from work in this area. (These can defined without use of the words 'physics' or 'quantum' but are nonetheless interesting.)

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Singular value decompostion based deep learning architecture for functional motion prediction of super-large protein complexes

Proteins usually fulfill their biological functions by interacting with other proteins. Although some methods have been developed to predict the functional motions of a monomer protein or small protein complexes. The correct prediction of the detailed functional motion of super-large protein complexes is still an open problem and has great significance for practical experimental applications in the life sciences. Here we report a new deep learning architecture based on singular value decomposition of coarse grained protein residue interaction network. Our method is efficient for simulating and predicting functional motions of super-large protein complexes, which will be helpful for biological applications.

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Low-rank functional decompositions with applications to stochastic optimal control

We describe a new function approximation framework based on a continuous extension of the tensor-train decomposition. The approximation, termed a function-train (FT), results in a tensor-train structure whose cores are univariate functions. An advantage of the FT over discrete approaches is that it produces an adaptive approximation of univariate fibers that is not tied to any tensorized discretization; indeed, the algorithm can be coupled with any univariate linear or nonlinear approximation procedure. Furthermore, the representation of low-rank functions in FT format enables efficient continuous computation: we can add, multiply, integrate, and differentiate functions in polynomial time with respect to dimension. We also describe a low-rank solver for non-linear and non-affine stochastic optimal control problems. Our approach is equivalent to solving multidimensional Hamilton-Jacobi-Bellman partial differential equations. We demonstrate its capabilities by solving problems with more than 10^8 unknowns with a single CPU core.

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Equiangular line systems in Euclidean space

Given some dimension d, what is the maximum number of lines in $\mathbb{R}^d$ such that the angle between any pair of lines is constant? (Such a system of lines is called 'equiangular'.) This classical problem was initiated by Haantjes in 1948 in the context of elliptic geometry. In 1966, Van Lint and Seidel showed that graphs could be used to study equiangular line systems.

Recently this area has enjoyed a renewed interest due to the current attention the quantum information community is giving to its complex analogue. I will report on some new developments in the theory of equiangular lines in Euclidean space, including recent improvements to the upper bounds on the maximum number of equiangular lines in $\mathbb{R}^d$ for some d.

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The Nonlinear Eigenvalue Problem

Given a matrix-valued function $F : \mathbb{C} \supseteq \Omega \to \mathbb{C}^{n\times n}$, the basic nonlinear eigenvalue problem consists of finding scalars $z \in \Omega$ for which $F(z)$ is singular. Such problems arise in many areas of computational science and engineering, including acoustics, control theory, fluid mechanics, and structural engineering.

In this talk I will discuss some interesting mathematical properties of nonlinear eigenvalue problems and then review recently developed algorithms for their numerical solution. Emphasis will be given to the linear algebra problems to be solved in these algorithms and to the choice of parameters.

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Quantum walks and graph isomorphism

A quantum walk is a quantum process on a graph, which can be used to implement a universal model of quantum computation. In this talk, we will discuss discrete-time quantum walks. Emms, Hancock, Severini and Wilson proposed a graph isomorphism routine for the class of strongly regular graphs, based on the spectrum of a matrix related to the discrete-time quantum walk. We give counterexamples to this conjecture. Another matrix related to the discrete-time quantum walk has been independently studied as the Bass-Hashimoto edge adjacency operator, in the context of the Ihara zeta function of graphs. We find its spectrum for the class of regular graphs. We will also discuss a result about the cycle space of line digraphs of graphs, which is motivated by the previous problems. This is joint work with Chris Godsil and Tor Myklebust.

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Constructions of optimal like packings with DFT matrices

In this talk, we consider the problem of constructing optimal packings of n complex lines in $\mathbb{C}^d$ - or, equivalently, sets of n complex d-dimensional unit vectors for which the largest absolute inner product between distinct vectors is minimal.

By exploiting certain DFT matrices and well-known group-theoretic/combinatorial objects - difference sets and relative difference sets - we produce two new infinite families of optimal line packings. In particular, whenenever $d-1$ is a prime power, we construct an optimal packing of $n = d^2 + 1$ lines in $\mathbb{C}^d$ and whenever d is a prime power, we construct an optimal packing of $n = d^2+d-1$ lines in $\mathbb{C}^d$. Moreover, we show that these constructions correspond to (weighted) complex projective 2-designs, which can be useful in quantum state tomography.

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Spectral characterizations of graphs

Spectral graph theory deals with the relation between the structure of a graph and the eigenvalues (spectrum) of an associated matrix, such as the adjacency matrix A and the Laplacian matrix L. Many results in spectral graph theory give necessary condition for certain graph properties in terms of the spectrum of A or L. Typical examples are spectral bounds for characteristic numbers of a graph, such as the independence number, the chromatic number, and the isoperimetric number. Another type of relations are characterization. These are conditions in terms of the spectrum of A or L, which are necessary and sufficient for certain graph properties. Two famous examples are: (i) a graph is bipartite if and only if the spectrum of A is invariant under multiplication by -1, and (ii) the number of connected components of a graph is equal to the multiplicity of the eigenvalue 0 of L.

In this talk we will survey graph properties that admit such a spectral characterization. In the special case that the graph itself is characterized by the spectrum of A or L, we say that the graph is determined by the considered spectrum. Although many graphs are not determined by the spectrum of A or L it is conjectured that almost all graphs are determined by their adjacency spectrum (and perhaps also by the Laplacian spectrum). We will report on recent results concerning this conjecture.

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Maehara's Conjecture, the Delta Theorem, and the greedegree of a graph

The minimum degree $\delta(G)$ of a graph G was conjectured as a combinatorial lower bound for the maximum nullity $M(G)$ at the same 2006 workshop that introduced the zero forcing number $Z(G)$ as a combinatorial upper bound. The conjectured bound $\delta(G) \leq M(G)$ was subsequently discovered to be strictly implied by a still-open 1987 conjecture of Maehara, which in turn was strengthened in 2008 to the conjecture $\delta(G) \leq \nu(G)$, where $\nu(G)$ is the maximum nullity that can be achieved by a positive semidefinite matrix satisfying the Strong Arnold Property.

The method of proof for the theorem $\delta(G) \leq \nu(G)$ gives, in fact, a sometimes better bound, still combinatorial in nature, which is introduced as the *greedegree of* G, denoted ${}^g\Delta(G)$. By the minor monotonicity of ν, the yet improved bound $\lceil {}^g\Delta(G) \rceil \leq \nu(G)$ holds as well.

A *greedy ordering* on the vertices of G is an ordering that adds successive vertices to induced subgraphs of G in such a way as to maximize the new edges added at each choice, and ${}^g\Delta(G)$ is the maximum, over all such orderings, of the degree of the final vertex added.

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Compressed Sensing from Phaseless Gaussian Measurements via Linear Programming in the Natural Parameter Space

We consider faithfully combining phase retrieval with classical compressed sensing. Inspired by the recent novel formulation for phase retrieval called PhaseMax, we present and analyze SparsePhaseMax, a linear program for phaseless compressed sensing in the natural parameter space. We establish that when provided with an initialization that correlates with an arbitrary k-sparse n-vector, SparsePhaseMax recovers this vector up to global sign with high probability from O(k log(n/k)) magnitude measurements against i.i.d. Gaussian random vectors. Our proof of this fact exploits a curious newfound connection between phaseless and 1-bit compressed sensing. This is the first result to establish bootstrapped compressed sensing from phaseless Gaussian measurements under optimal sample complexity.

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Peierls-Bogolyubov's inequality for deformed exponentials

We study convexity or concavity of certain trace functions for the deformed logarithmic and exponential functions, and obtain in this way new trace inequalities for deformed exponentials that may be considered as generalizations of Peierls-Bogolyubov's inequality. We use these results to improve previously known lower bounds for the Tsallis relative entropy.

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The Learning and Teaching of Linear Algebra Through the Lenses of DNR-Based Instruction in Mathematics

DNR-based instruction in mathematics (DNR, for short) is a theoretical framework for the learning and teaching of mathematics–a framework that provides a language and tools to formulate and address critical curricular and instructional concerns. DNR can be thought of as a system consisting of three categories of constructs: premises–explicit assumptions underlying the DNR concepts and claims; concepts–constructs oriented within these premises; and claims–statements formulated in terms of the DNR concepts, entailed from the DNR premises, and supported by empirical studies.

The main goal of this talk is to discuss cognitive and pedagogical aspects of linear algebra through the lenses of DNR. The presentation will include observations made in teaching experiments in linear algebra we have conducted during the years, which will illustrate the role and function of various DNR constructs in the learning and teaching of linear algebra.

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On Element-wise and Block-wise Jacobi Methods for PGEP

We derive and analyze new Jacobi methods for the positive definite generalized eigenvalue problem (PGEP) $Ax = \lambda Bx$, where A and B are complex Hermitian matrices and B is positive definite. They are based on LL^*, RR^* and the spectral decomposition of the pivot submatrix of B, followed by the Jacobi transformation for the updated pivot submatrix of A. In addition, we analyze a hybrid method, which combines these three methods, and a general Jacobi method for PGEP. The global convergence of those methods is proved under the large class of generalized serial strategies. High relative accuracy and asymptotic convergence of those methods have also been investigated.

These element-wise methods can well serve as kernel algorithms for the associated block Jacobi methods which are suitable for large-scale CPU and GPU computing. When implemented as one-sided block methods for the generalized singular value problem, they are very efficient, and as numerical tests indicate highly accurate on well behaved matrices. The global convergence of the block methods under the generalized serial strategies has also been investigated.

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Stable inversion of (certain) random periodic feature maps

We consider a class of inverse problems where a high-dimensional unknown parameter vector is embedded into a lower-dimensional space using a randomized, periodic feature map. Examples of such embeddings arise in applications such as machine learning and high dynamic range (HDR) imaging.

In this work, we demonstrate that with a mild increase in the dimension of the embedding, it is also possible to stably reconstruct the data vector from such random feature maps, provided that the underlying data is sparse enough. In particular, we propose a simple, numerically stable algorithm for reconstructing the data vector given the nonlinear features. We support the efficacy of our approach via rigorous analysis as well as numerical experiments.

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Second Order Riemannian Methods for Low-Rank Tensor Completion

The goal of tensor completion is to fill in missing entries of a partially known tensor (possibly inculding some noise) under a low-rank constraint. This may be formulated as a least-squares problem. The set of tensors of a given multilinear rank is known to admit a Riemannian manifold structure, thus methods of Riemannian optimization are applicable.

In our work, we derive the Riemannian Hessian of an objective function on the low-rank tensor manifolds and discuss the convergence properties of second order methods for the tensor completion problem, both theoretically and numerically. We show the applicability of a Riemannian limited-memory BFGS scheme to this problem. We compare our approach to Riemannian tensor completion methods from recent literature.

Our examples include the recovery of multidimensional images, approximation of multivariate functions and recovery of partially missing data from survey statistics.

This is joint work with Volker Schulz (*Trier University*). This work was supported by the German Research Foundation (DFG) within the Research Rraining Group 2126 'Algorithmic Optimization'.

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Continuum limits for shortest paths

Many applications involve computing shortest paths over the nodes of a graph relative to a measure of pair-wise node dissimilarity. When the node attributes are real valued random vectors and the dissimilarity is an increasing function of Euclidean distance these shortest paths can have continuum limits as the number of nodes approaches infinity. Such continuum limits can lead to low complexity continuous diffusion approximations to the combinatorial shortest path problem. This work is joint with Sung Jin Hwang and Steven Damelin and was supported in part by NSF Grant CCF-1217880 and ARO grant W911NF-15-1-0479.

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Log-majorization and Lie-Trotter formula for the Cartan barycenter

Let $\mathbb{P}_n$ be the set of $n \times n$ positive definite matrices. The geometric mean introduced by Pusz and Woronowicz is defined as

$$G(A,B) = A \# B := A^{1/2}(A^{-1/2}BA^{-1/2})^{1/2}A^{1/2}, \qquad A, B \in \mathbb{P}_n,$$

which is, except for the arithmetic and the harmonic means, the most studied operator mean. The weighted geometric means $A \#_t B := A^{1/2}(A^{-1/2}BA^{-1/2})^t A^{1/2}$ $(0 \le t \le 1)$ form the geodesic joining A, B in the Riemannian manifold $\mathbb{P}_n$ with the Riemannian distance $\delta(A,B) := \| \log A^{-1/2}BA^{-1/2}\|_2$. In the last decade there have been quite big advances, in the Riemannian geometric approach, on the multivariate extension of the geometric mean, with different names such as the Riemannian mean, the least squares mean, the Karcher mean, etc. Let $\mathcal{P}^1(\mathbb{P}_n)$ be the set of probability measures μ such that $\int_{\mathbb{P}_n} \delta(X,Y)\,\mu(X) < +\infty$ for some (equivalently for all) $Y \in \mathbb{P}_n$. The most general extension of the geometric mean, which we call the Cartan barycenter, is defined for $\mu \in \mathcal{P}^1(\mathbb{P}_n)$ as

$$G(\mu) := \operatorname*{arg\,min}_{Z \in \mathbb{P}_n} \int_{\mathbb{P}_n} \left[\delta^2(Z,X) - \delta^2(Y,X)\right] d\mu(X)$$

independently of the choice of a fixed $Y \in \mathbb{P}_n$. In the talk we discuss the following two topics on $G(\mu)$.

(1) **Log-majorization of Ando-Hiai:**

$$G(\mu^r) \prec_{\log} G(\mu)^r, \qquad r \ge 1.$$

To show this, we develop the antisymmetric tensor power technique for $G(\mu)$.

(2) **Lie-Trotter formula:**

$$\lim_{r \to 0} G(\mu^r)^{1/r} = \exp \int_{\mathbb{P}_n} \log X \, d\mu(X).$$

The usual technique to prove this is the arithmetic-geometric-harmonic mean inequality. However, we cannot use it in the present case since the arithmetic and the harmonic means cannot be defined for general $\mu \in \mathcal{P}^1(\mathbb{P}_n)$.

The talk is based on joint work with Yongdo Lim.

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On meta-thin association schemes with certain conditions

Let(X,S) be an association scheme where X is a finite set. We say that (X,S) is *meta-thin* if the thin residue of S is contained in the thin radical of S. In this talk we show some sufficient conditions for a meta-thin association scheme to be obtained from a transitive action on X.

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Eigenvalue location for graphs of small clique-width

Let $G = (V, E)$ be a graph with adjacency matrix A. A classical theorem of Sylvester tells us that finding the number of eigenvalues of A in a given interval is closely related with obtaining, for any real constant c, a diagonal matrix D_c congruent to $A-cI$. Indeed, the number of eigenvalues of A greater than c equals the number positive entries in D_c. (Similarly, the number of eigenvalues equal to c, or less than c, are given by the number of zero diagonal entries, or by the number of negative entries in D_c, respectively.) Our contribution deals with the design of such a diagonalization algorithm based on the *clique-width decomposition* of a graph G. This decomposition was introduced in 2000 by Courcelle and Olariu, and turns out to be quite useful for algorithmic purposes. Its main motivation was to extend the well-known concept of tree-width, due to Robertson and Seymour, to denser graphs. Our algorithm has the property that, if G has clique-width k and a corresponding decomposition is known, then diagonalization can be done in time $O(k^3 n)$ where n is the order of G. This parameterized complexity view is very powerful. On the one hand, for constant k, we turn a cubic time solution into a linear time solution. On the other hand, the structure of the algorithm allows us to derive theoretical results about the spectrum of special classes of graphs.

This is joint work with Martin Frer (Pennsylvania State University), David Jacobs (Clemson University) and Vilmar Trevisan (Universidade Federal do Rio Grande do Sul).

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Entropy exchange for infinite-dimensional systems

The entropy exchange for channels and states in infinite-dimensional systems are defined and studied. It is shown that, this entropy exchange depends only on the given channel and the state. An explicit expression of the entropy exchange in terms of the state and the channel is proposed. The generalized Klein's inequality, the subadditivity and the triangle inequality about the entropy for the infinite-dimensional systems are proved and then, applied to compare the entropy exchange with the entropy change.

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Cyclic weighted shift matrix with reversible weights

Using the Helton-Vinnikov Theorem, Helton and Spitkovsky proved that the numerical range $W(A)$ of an arbitrary $n \times n$ matrix A has some $n \times n$ complex symmetric matrix S satisfying $W(A) = W(S)$. Since the numerical range is invariant under the unitary similarity, these results arise a new motivation to consider a question: What matrix A is unitarily similar to a complex symmetric matrix. In this talk, we characterize a special type of matrix is complex symmetric under the Fourier matrix.

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Intrinsic Representation of Tangent Vectors and Vector transport on Matrix Manifolds

The quasi-Newton methods on Riemannian manifolds proposed thus far do not appear to lend themselves to satisfactory convergence analyses unless they resort to an isometric vector transport. This prompts us to propose a computationally tractable isometric vector transport on commonly-encountered manifolds, namely the Stiefel manifold, the Grassmann manifold, the fixed-rank manifold, and the positive-(semi)definite fixed-rank manifold. In this process, we also propose a convenient way to represent tangent vectors to these manifolds as elements of $\mathbb{R}^d$, where d is the dimension of the manifold. We call this an 'intrinsic' representation, as opposed to 'extrinsic' representations as elements of $\mathbb{R}^w$, where w is the dimension of the embedding space. In this presentation, we discuss the intrinsic representation of tangent vectors and a cheap isometric vector transport using the representation. A limited-memory version of Riemannian BFGS method (LRBFGS) is used as an example to show the details of implementations. Its computational complexities are reported to compare with a conventional approach. Finally, numerical experiments are given to demonstrate the performance of the proposed isometric vector transport.

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Phase Retrieval with Noise and Outliers

In the phase retrieval problem, data can contain many outliers. For example, highly corrupted measurements can appear from sensor failure and preprocessing steps. In this talk, I will discuss the so-called RobustPhasemax convex program that can approximately recover an unknown signal from quadratic measurements in the presence of noise and corruption. This is joint work with Paul Hand and Vladislav Voroninski.

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Approximate Latin squares and triply stochastic cubic tensors

Triply stochastic cubic tensors are decompositions of the all-ones matrix as the sum of an ordered set of bistochastic matrices. They combine to yield so-called weak approximate Latin squares. Approximate symmetry, as implemented by the stochastic matrix actions of quasigroups on homogeneous spaces, extends the concept of exact symmetry as implemented by permutation matrix actions of groups on coset spaces. Now approximate Latin squares are described as being strong if they occur within quasigroup actions. We study these weak and strong Latin squares, in particular examining the location of the latter within the polytope of triply stochastic cubic tensors.

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On Incidence Algebras and their Representations

Incidence algebras of posets, or structural matrix algebras, have been studied from various perspectives, including combinatorics, linear algebra, representation theory. We introduce a deformation theory for such algebras, in terms of the simplicial realization of the underlying poset, and give a unified approach to understanding several classes of representations (such as with finitely many orbits, with finitely many invariant subspaces, or which are distributive, or which are thin, i.e. the multiplicity of each simple in the composition series is less than 1). We and give a series of applications.

First, we give new characterizations of incidence algebras (as algebras with a faithful distributive representation) and show that their deformations are exactly the locally hereditary algebras which are semi-distributive or have finitely many ideals. Second, we give a complete classification of all thin and all distributive representations of incidence algebras. Furthermore, we extend this to arbitrary algebras and provide a method to completely classify thin representations over any algebra. As a consequence, we obtain the following 'generic classification': we show that any thin representation of any algebra, and any distributive representation of an acyclic algebra can be presented, by choosing suitable bases and after canceling the annihilator, as the defining representation of an incidence algebra.

Time permitting, we discuss other applications, such as consequences on the structure of representation and Grothendieck rings of incidence algebras, and an answer to a conjecture of Bongartz and Ringel, in a particular case.

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Randomized matrix-free trace and log-determinant estimators

We present randomized algorithms for estimating the trace and determinant of Hermitian positive semi-definite matrices. The algorithms are based on subspace iteration, and access the matrix only through matrix vector products. We analyse the error due to randomization, for starting guesses whose elements are Gaussian or Rademacher random variables. The analysis is cleanly separated into a structural (deterministic) part followed by a probabilistic part. Our absolute bounds for the expectation and concentration of the estimators are non-asymptotic and informative even for matrices of low dimension. For the trace estimators, we also present asymptotic bounds on the number of samples (columns of the starting guess) required to achieve a user-specified relative error.

This is joint work with Alen Alexanderian and Arvind Saibaba. The work is supported in part by the XDATA Program of the Defense Advanced Research Projects Agency.

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Compactness of operators on Bergman and Fock spaces

We discuss the compactness of operators on Bergman and Fock spaces in terms of the Berezin transform of the operator. Furthermore, we discuss some related essential norm estimates. This is partly joint work with Mishko Mitkovski and Brett Wick.

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Estimations of power difference mean by Heron mean

As generalizations of arithmetic and geometric means, for positive real numbers a and b, power difference means $J_q(a,b) = \frac{q}{q+1}\frac{a^{q+1}-b^{q+1}}{a^q-b^q}$ and Heron means $K_q(a,b) = (1-q)\sqrt{ab} + q\frac{a+b}{2}$ are well known. By Kubo-Ando theory on operator means, we can also consider these means for positive bounded linear operators on a Hilbert space.

In this talk, we obtain the greatest value $\alpha = \alpha(q)$ and the least value $\beta = \beta(q)$ such that the double inequality

$$K_\alpha(a,b) < J_q(a,b) < K_\beta(a,b)$$

holds for any $q \in \mathbb{R}$, which includes Xia, Hou, Wang and Chu's result. Moreover, from this result, we get similar operator inequalities including Fujii, Furuichi and Nakamoto's result on estimations of Heron means.

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Hadamard powers of two classes of positive matrices

It is known that $n-2$ is the least number for which the rth Hadamard power of an $n \times n$ doubly nonnegative matrix is doubly nonnegative for all $r \geq n-2$. An analogous result holds for positive semidefinite matrices with real (not necessarily nonnegative) entries. We shall discuss two interesting classes of positive semidefinite matrices whose rth Hadamard powers need not be positive semidefinite for $r < n-2$. In particular we shall focus on the $n \times n$ matrices, $[(1+x_ix_j)^r]$ and $[|\cos((i-j)\pi/n)|^r]$ where r is a positive number and $x_1, \ldots, x_n$ are distinct positive real numbers.

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The infinite bi-Lanczos method for nonlinear eigenvalue problems

We propose a two-sided Lanczos method for the nonlinear eigenvalue problem (NEP). This two-sided approach provides approximations to both the right and left eigenvectors of the eigenvalues of interest. The method implicitly works with matrices and vectors with infinite size, but because particular (starting) vectors are used, all computations can be carried out efficiently with finite matrices and vectors. We specifically introduce a new way to represent infinite vectors that span the subspace corresponding to the conjugate transpose operation for approximating the left eigenvectors. Furthermore, we show that also in this infinite-dimensional interpretation the short recurrences inherent to the Lanczos procedure offer an efficient algorithm regarding both the computational cost and the storage.

This is joint work with S. Gaaf, TU Eindhoven.

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Non-negative Matrix Factorization Revisited

Given a data matrix, a useful way to analyze its structure consists in expressing its rows -approximately- as convex combinations of a set of 'archetypes'. Versions of this idea have been applied within network analysis, information retrieval, hyperspectral imaging, blind source separation and so on. Algorithms and theoretical guarantees for this problem have been studied in statistics, theoretical computer science and optimization, often under the name of non-negative matrix factorization. Until recently, methods with rigorous guarantees were limited to the case in which the archetypes appear among the observed data (separability). We will discuss a new approach that does not assume separability.

This is based on a joint work with Andrea Montanari.

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The operator monotonicity of k-isotropic functions

A function F from the space of $n \times n$ symmetric matrices S^n to the space $S^{\binom{n}{k}}$, for some $k = 1, \ldots, n$, is called k-*isotropic* if it satisfies the invariance property

$$F(UXU^T) = U^{(k)}F(X)(U^{(k)})^T$$

for all $X \in S^n$ in the domain of F and all $n \times n$ orthogonal matrices U. (Here, $U^{(k)}$ denotes the k-th multiplicative compound matrix derived from U.) It can be shown that every k-isotropic function can be represented as

$$F(X) = U^{(k)}\big(\mathrm{Diag} f(\lambda(X))\big)(U^{(k)})^T$$

for some unique function $f : \mathrm{R}^n \to \mathrm{R}^{\binom{n}{k}}$ having a symmetric property, where $X = U(\mathrm{Diag}\lambda(X))U^T$ is the ordered spectral decomposition of X.

These maps generalize and extend three types of previously well-studied functions. For example, when $k = 1$, we obtain the so-called tensor-valued isotropic functions; when $k = 1$ and $f(x) = (g(x_1), \ldots, g(x_n))$, we obtain the primary matrix functions; and when $k = n$ and f is symmetric, we obtain the spectral functions. In general, we say that f *is generated* when $f_\rho(x) = g(x_{\rho_1}, \ldots, x_{\rho_k})$ for some symmetric function $g : \mathrm{R}^k \to \mathrm{R}$, where ρ is any k-element subset of $\{1, \ldots, n\}$ used to index the entries of $f(x)$.

We are interested in the operator monotonicity of k-isotropic functions in the case when f is generated by a function g. We show that the corresponding k-isotropic function is operator monotone if and only if g is operator monotone, in the classical sense, with respect to each variable. Conversely, starting with an operator monotone function $h : (0, \infty) \to (0, \infty)$, let $g : \mathrm{R}^k \to \mathrm{R}$ be the k-th divided difference of h (with appropriate sign), and let $f : \mathrm{R}^n \to \mathrm{R}^{\binom{n}{k}}$ be generated by g. Then, the k-isotropic function corresponding to f is operator monotone.

By restricting a k-isotropic function to block-diagonal matrices, one obtains a matrix-valued function on several matrix variables. In this way, our results extend previous work on operator monotonicity of function on several matrix variables.

This is joint work with Hristo S. Sendov.

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Triangular matrices and combinatorial recurrences

In this work we introduce the triangular arrays of depth greater than 2, some infinite lower triangular matrices whose entries are determined by recurrence relations that generalize some well-known recurrences that appear in enumerative combinatorics. Specifically, given $n \in \mathbb{N}^*$ we say that $T = \big(t_{k,m}\big)_{k,m\geq 0}$ is a *triangular matrix of depth* n if $t_{k,m} = 0$ for $0 \leq k < nm$. Of course, triangular matrices of depth 1 are the usual lower triangular matrices and triangular matrices of depth $n \geq 2$ are those lower triangular matrices, that in column m the first nm entries are null. The triangular matrices we consider here are determined by linear recurrence relations: given two infinite matrices $g = (g_{k,m})$, $h = (h_{k,m})$, for any $n \in \mathbb{N}^*$ we define the triangular matrix of depth n, $T = (t_{k,m})$, as

$$t_{0,0} = 1 \quad \text{and} \quad t_{k,m} = g_{k-1,m}t_{k-1,m} + h_{k-n,m-1}t_{k-n,m-1}, \quad k \geq nm; \quad m \geq 0, \quad k + m \geq 1. \tag{2}$$

The linear character of the above recurrence allows us to solve it by determining each *column* in terms of the preceding ones. Therefore, for any $n \in \mathbb{N}^*$, there exists a unique triangular matrix of depth n, denoted by $\mathscr{G}_n(g, h)$, satisfying this recurrence and g and h are then called its *generators*. The class triangular matrices of the form $\mathscr{G}_1(g, h)$ are also known as *pure Galton arrays* and have been well studied since they are closely related with combinatorial recurrences. However, triangular matrices of the form $\mathscr{G}_n(g, h)$ for $n \geq 2$ are still unknown. In particular, we are mainly focussed in studying those triangular matrices of depth 2, whose generators are column independent; that is, are given by sequences $g = (g_k)$ and $h = (h_k)$. We will show how this triangular matrices appear as essential components in the expression of the solution of initial value problems for homogeneous second order difference equations, linking in this way lower triangular matrices $\mathscr{G}_2(g, h)$ with some classical orthogonal polynomials and combinatorial numbers. As a by-product we obtain that an irreducible second order linear difference equation can be solved by means of a sequence of first order linear difference equations, which represent a huge distinction between the treatment of differential and difference linear equations.

This is a joint work with Andrés M. Encinas. This work has been partly supported by the Spanish Research Council under project MTM2014-60450-R.

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Recent Progress on Block Krylov Subspace Methods for Linear Systems with Multiple Right-hand Sides

Solving a sequence of large linear systems with several right-hand sides given simultaneously or in sequence, is at the core of many problems in the computational sciences, such as in radar cross section calculation in electromagnetism, wave scattering and wave propagation in acoustics, uncertainty quantification, quantum chromodynamics, data handling, time-dependent problems, and various source locations in seismic and parametric studies in general.

In that framework, block Krylov approaches appear as good candidates for the solution as the Krylov subspaces associated with each right-hand side are shared to enlarge the search space. They are attractive not only because of this numerical feature (larger search subspace), but also from a computational view point as they enable higher data reusability consequently locality (BLAS3-like implementation). These nice data features comply with the memory constraint of modern multicore architectures.

In this talk, we give a brief overview of relevant recent Krylov subspace methods and then introduce two newly-developed block Krylov methods for linear systems with multiple right-hand sides available in two situations. For 'simultaneous' right-hand sides, a block GMRES method is presented, which can address the problems related to spectral augmentation at restart and partial convergence of some linear combinations of the right-hand sides. For right-hand sides available one after each other, including the case where there are massive number (like tens of thousands) of right-hand sides associated with a single matrix so that all of them cannot be solved at once but rather need to be split into chunks of possible variable sizes, a recycling block flexible –GMRES″ variant is developed by combining sub-space augmentation techniques in the generalized minimum residual norm framework to recycle spectral information between each restart and each block of right-hand sides, inexact breakdown detection in such a sub-space augmentation, and flexible preconditioner to cope with constraints on some applications while also enabling mixed-precision calculation. We demonstrate the efficiency of the two new algorithms on a set of numerical experiments including mixed arithmetic calculations.

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Quantum Coherence and Quantum Entanglement

There are two key ingredients that make quantum information theory different from classical information theory: entanglement and superpositions. Various measures of quantum entanglement have been investigated for years, but measures of coherence (i.e., 'how superpositioned' a quantum state is) are a bit less well-studied. In this talk we will discuss some ways of measuring coherence, and in general how to turn an entanglement measure into a coherence measure.

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Singular M-matrices: Some Recent Results

For a matrix A whose off-diagonal entries are nonpositive, its nonnegative invertibility (namely, that A is an invertible M-matrix) is equivalent to A being a P-matrix, which is necessary and sufficient for the unique solvability of the linear complementarity problem defined by A. This, in turn, is equivalent to the statement that A is strictly semimonotone. In this talk, we will be presenting analogues of this result for singular symmetric Z-matrices. This is achieved, among other things, by replacing the inverse of A by the group generalized inverse. Two other extensions of M-matrix results will also be presented.

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Rational filtering Schur complement techniques for the solution of large-scale generalized symmetric eigenvalue problems

This paper considers contour integration domain decomposition techniques for the solution of large and sparse real symmetric generalized eigenvalue problems. The proposed technique is purely algebraic and decomposes the original eigenvalue problem defined in each subdomain into two different parts. The first part is interior to each subdomain and can be solved in trivial parallelism among the different subdomains using real-arithmetic only. The second part is associated with the interface variables and accounts for the interaction between neighboring subdomains. To solve the interface eigenvalue problem, we consider leveraging ideas from contour integration-type eigenvalue solvers. Overall, the proposed technique integrates the matrix resolvent only partially and applies any orthogonalization necessary only to vectors whose length is equal to the number of interface variables. Numerical experiments performed in serial and distributed memory architectures verify the competitiveness of the proposed technique against rational Krylov approaches.

This is joint work with Yuanzhe Xi and Yousef Saad. This work supported jointly by NSF under award CCF-1505970 (theoretical aspects) and by the Scientific Discovery through Advanced Computing (SciDAC) program funded by U.S. Department of Energy, Office of Science, Advanced Scientific Computing Research and Basic Energy Sciences under award number DE-SC0008877 (Implementations, application to DFT).

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Computational Approaches for Minimum Rank Problems and their Variations

The minimum rank problem asks to find the minimum rank over all matrices with a given pattern associated with a graph. This problem is NP-hard, and there is no known approximation method. Further, this problem has no straightforward convex relaxation. We give a numerical algorithm to heuristically approximate the minimum rank using alternating projections. The effectiveness of this algorithm is demonstrated by using the zero-forcing number. We apply this algorithm to provide numerical evidence for several outstanding conjectures regarding the minimum rank. Using this technique, we also explore variations of the minimum rank problem as well as their corresponding zero-forcing parameters.

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New Functionality in the FEAST Eigenvalue Solver

The FEAST algorithm is a robust contour integral technique for solving interior eigenvalue problems. This talk will discuss new functionality in v3.0 of the package, which includes support for non-Hermitian problems. The next update will also add a third level of MPI parallelism by linking with distributed memory linear solvers. Written with an RCI mechanism, any solver can be interfaced with the software kernel. Scalability and performance results from a 3-dimensional finite element electronic structure calculation will be presented.

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Generalized nil-Coxeter algebras over complex reflection groups

We define and study generalized nil-Coxeter algebras associated to Coxeter groups. Motivated by a question of Coxeter (1957), we construct and study the first such examples of finite-dimensional algebras that are not 'usual' nil-Coxeter algebras: a novel 2-parameter family that we call $NC_A(n,d)$.

Further motivated by the Broue-Malle-Rouquier freeness conjecture, we define generalized nil-Coxeter algebras NC_W over all discrete complex reflection groups W, and classify the finite-dimensional ones among them. Remarkably, these turn out to be only the usual nil-Coxeter algebras and the algebras $NC_A(n,d)$. In particular, generic Hecke algebras are not flat deformations of NC_W for W complex. Our proofs are based on a diagrammatic calculus akin to crystal theory.

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Riordan matrices related to the Mertens function

The Redheffer matrix R_n is defined as an $n \times n$ matrix whose (i, j)-entry is 1 if either $j = 1$ or i divides j, and 0 otherwise. It is well known that the Riemann hypothesis is true if and only if

$$\det R_n = O(n^{1/2+\epsilon})$$

for all positive ϵ. The determinant is known to be $\sum_{k=1}^{n} \mu(k)$, the Mertens function, where $\mu(k)$ is the Möbius function. Many algebraic properties of the Redheffer matrix have been studied including eigenvalues, eigenvectors, characteristic polynomials, etc., though no rigorous argument on a direct connection to the Riemann hypothesis has been known so far.

In this talk, we introduce a new infinite family of matrices using Riordan matrices in which each has the same determinant as the Redheffer matrix but may have different eigenvalues. A Riordan matrix is an infinite lower triangular matrix whose (i, j)-entry is the coefficient of z^i in $g(z)f(z)^j$ for $i, j \geq 0$, where $g(z)$ and $f(z)$ are formal power series satisfying $g(0) = 1$, $f(0) = 0$ and $f(0) \neq 0$. We find the generating function for the characteristic polynomials of the new matrices. Some examples and conjectures will be also introduced.

This is joint work with Gi-Sang Cheon. This work was partially supported by National Institute of Mathematical Sciences (A23100000) and was partially supported by the National Research Foundation of Korea (NRF-2016R1C1B1014356).

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An order inequality characterizing Cartan barycenters of positive definite matrices

There are infinitely many invariant and contractive barycenters of probability measures on Hadamard spaces. We establish an order inequality of probability measures on the typical example of Hadamard spaces, the open convex cone of positive definite matrices, characterizing the Cartan barycenter among other invariant and contractive barycenters.

This is a joint work with Hosoo Lee and Yongdo Lim. This work was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science, ICT and Future Planning (2015R1C1A1A02036407).

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$(0,1)$ Matrices and the Analysis of Social Networks

In the analysis of social networks, sociologists deal with rectangular $(0,1)$ matrices known as actor-event matrices. Given such an $m \times n$ $(0,1)$ matrix, a common approach in the sociology literature is to work with the pair of matrices AA^T, A^TA instead of analysing A directly. The question then arises: under what circumstances do there exist pairs of $m \times n$ $(0,1)$ matrices A, B such that i) $AA^T = BB^T$ and ii) $A^TA = B^TB$?

In this talk we outline a technique for addressing that question. Using this technique, we construct an exponentially large family of $(n+1) \times 2n$ pairs of $(0,1)$ matrices satisfying i) and ii). This family has a surprising connection with regular tournament matrices.

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A generalization of the Ando-Hiai-Okubo trace inequalities

Let A be a positive semidefinite matrix and B be a Hermitian matrix. It is shown that

$$\mathrm{tr} A^{\alpha} B A^{\beta} B \leq \mathrm{tr} A^{\gamma} B A^{\delta} B$$

for all non-negative real numbers $\alpha, \beta, \gamma, \delta$ for which $\alpha + \beta = \gamma + \delta$ and

$$\max\{\alpha, \beta\} \leq \max\{\gamma, \delta\}.$$

This is a generalization of trace inequalities due to T. Ando, F. Hiai, and K. Okubo for the special cases when $\gamma = \alpha + \beta, \delta = 0$ and when $\alpha = \beta = \frac{\gamma+\delta}{2}$, namely

$$\mathrm{tr}(A^{\frac{\alpha+\beta}{2}} B)^2 \leq \mathrm{tr} A^{\alpha} B A^{\beta} B \leq \mathrm{tr} A^{\alpha+\beta} B^2.$$

Among other applications of our new trace inequality, we have the Hilbert-Schmidt norm inequality

$$\left\| A^{\alpha} B + B A^{\beta} \right\|_2 \leq \left\| A^{\gamma} B + B A^{\delta} \right\|_2,$$

where A is a positive semidefinite matrix, B is a Hermitian matrix, and $\alpha, \beta, \gamma, \delta$ are non-negative real numbers for which $\alpha + \beta = \gamma + \delta$ and

$$\max\{\alpha, \beta\} \leq \max\{\gamma, \delta\}.$$

This is joint work with M. Hayajneh and S. Hayajneh.

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Intrinsic Metrics on Graphs and Applications

Graphs are a cosmopolitan representation for a diversity of things: group networks in sociology, food-webs in biology, Feynman diagrams in physics, electrical circuits in engineering, and molecular structures in chemistry. Graph characteristics are of interest, including intrinsic metrics. Besides the shortest-path metric, there are other possible candidates, involving: wave-amplitude correlations; numbers of vertex-distinguished spanning bi-trees; random walks between vertices; inversions of neighborliness measure; or effective electrical resistances between vertices. Granted a metric, there are associated graph invariants. Comparison of the proposed metrics to the shortest-path metric might measure 'cyclicity'. Variation of overall distances upon change in weight of an edge might measure 'centrality of the edge. Classical Euclidean-geometry might be a source of analogs for: linear curvature, torsion, Gaussian curvature, & mean volumina. Comparison's to Euclidean metrics of an embedding might measure 'crumpledness'. A kind of 'graph geometry' emerges.

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Condition Number of Krylov Matrices and Subspaces via Kronecker Product Structure

With the rise of s-step Krylov methods, the conditioning of Krylov matrices has become an important issue in determining the applicability of certain preconditioners and Newton bases. In order to help with the study of these problems, we improve previous algorithms and theoretical bounds pertaining to the condition number of Krylov matrices.

In particular, we tighten bounds on the condition number of Krylov matrices, first developed by Carpraux, Godunov, and Kuznetsov, by identifying and exploiting a Kronecker product structure inherent in the problem. Using this structure, we are able to formalize certain heuristics for designing preconditioners for GMRES, as well as provide new directions to relate Kronecker products with Krylov-based methods in the future.

This is joint work with David Imberti at INRIA.

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Visualizations and the Concept of Proof in Basic Linear Algebra Teaching

Understanding the concept of proof is an important challenge and goal of mathematics education. To teach students to comprehend and distinguish true from false reasoning, we should probably more often consider and analyze false arguments – rather than adhering to flawless deductive arguments, which are the only acceptable in (sophisticated mathematical) argumentation. This is especially important in the initial and basic mathematics education. To develop student's sensitivity for logical argumentation, understanding should first mean 'grasping the meaning' of different concepts and ideas. In basic Linear Algebra teaching visualizations and inductive arguments can lead to creative observations and intuitive meanings, bringing the challenge of uncertainty and curiosity, which are the best motivators and predecessors of a proof.

We will show examples, where simple computer technology is used to visualize specific basic Linear Algebra concepts in a way to intuitively enhance the meaning and create the need for (the concept of) proof.

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Tensor Decomposition: A Mathematical Tool for Data Analysis and Compression

Tensors are multiway arrays, and tensor decompositions are powerful tools for data analysis and compression. In this talk, we demonstrate the wide-ranging utility of both the canonical polyadic (CP) and Tucker tensor decompositions with examples in neuroscience, chemical detection, and combustion science. The CP model is extremely useful for interpretation, as we show with an example in neuroscience. However, it can be difficult to fit to real data for a variety of reasons. We present a novel randomized method for fitting the CP decomposition to dense data that is more scalable and robust than the standard techniques. The Tucker model is useful for compression and can guarantee the accuracy of the approximation. We show that it can be used to compress massive data sets by orders of magnitude; this is done by determining the latent low-dimensional multilinear manifolds. Lastly, we consider the modelling assumptions for fitting tensor decompositions to data and explain alternative strategies for different statistical scenarios. This talk features joint work with Woody Austin (University of Texas), Casey Battaglino (Georgia Tech), Grey Ballard (Wake Forrest), Alicia Klinvex (Sandia), Hemanth Kolla (Sandia), and Alex Williams (Stanford University).

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Stability of control networks in stem cell lineages

Design principles of biological networks have been studied extensively in the context of protein-protein interaction networks, metabolic networks, and regulatory (transcriptional) networks. Here we consider regulation networks that occur on larger scales, namely, the cell-to-cell signaling networks that connect groups of cells in multicellular organisms. These are the feedback loops that orchestrate the complex dynamics of cell fate decisions and are necessary for the maintenance of tissue. We focus on 'minimal' networks, that is those that have the smallest possible numbers of controls. Using the formalism of digraphs, we show that in two-compartment lineages, reducible systems must contain two 1-cycles, and irreducible systems one 1-cycle and one 2-cycle; stability follows from the signs of the controls and does not require magnitude restrictions. In three-compartment systems, irreducible digraphs have a tree structure or have one 3-cycle and at least two more shorter cycles, at least one of which is a 1-cycle. With further work and proper biological validation, our results may serve as a first step toward an understanding of ways in which these networks become degraded in cancer.

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Some Theorems on the Core Inverse of Matrices and the Core Partial Ordering

In this talk, we derive some further results on the core inverse of matrices and the core partial ordering. First we treat two representations of core inverse obtained by Baksalary and Trenkler (2010, Linear and Multilinear Algebra) and derive maximal classes of matrices for which the representations are valid. Next we discuss several formulas on the core partial ordering presented by Malik (2013, Applied Mathematics and Computation), and extend them by deriving maximal classes of matrices for which the formulas remain true.

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Separability of three qubit X-states

We show that the converse of Guehne's criterion for separability of three qubit states holds for X-states, that is, for states with zero entries except for diagonals and anti-diagonals. We also introduce a norm with which the separability can be characterize, and compute this norm in some cases.

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The star-shapedness of a generalized numerical range

Let H_n be the set of all $n\times n$ Hermitian matrices, and H_n^m be the set of all m-tuples of $n\times n$ Hermitian matrices. For any $\mathbf{A}=(A_1,\ldots,A_m)\in H_n^m$, we define the (joint) unitary orbit of $\mathbf{A}$ as

$$\mathbf{U}(\mathbf{A}):=\{(U^*A_1U,\ldots,U^*A_mU): U \text{ is an } n\times n \text{ unitary matrix}\}.$$

For any linear map $L: H_n^m\to\mathbb{R}^\ell$, we define the L-numerical range A as

$$W_L(\mathbf{A}):=L(\mathbf{U}(\mathbf{A}))=\{L(\mathbf{X}):\mathbf{X}\in\mathbf{U}(\mathbf{A})\},$$

which can be regarded as a generalization of the C-numerical range, the joint numerical range, etc. In the talk, we shall show that if $\ell\le 3$, $n\ge\ell$ and $A_1,\ldots,A_m$ are commute, then $W_L(\mathbf{A})$ is star-shaped with star-center at $L\left(\frac{\mathrm{tr}A_1}{n}I_n,\ldots,\frac{\mathrm{tr}A_m}{n}I_n\right)$.

This is a joint work with with TW Ng and NK Tsing.

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The Karcher Barycentric Map for Positive Operator Probability Measures on Hilbert Space

The multivariable matrix geometric mean extends to the space of positive operators on a Hilbert space as the solution of the Karcher equation and it has recently been shown that the latter extends uniquely to a barycentric map on the Wasserstein metric space of probability measures on the open cone of positive operators equipped with the Thompson metric. We discuss recently derived properties of this barycentric map such as monotonicity, approximation by power means, and its satisfaction of the Karcher equation.

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Spectral study of $\{R, s+1\}$-potent matrices

A matrix $A \in \mathbb{C}^{n\times n}$ is called $\{R, s+1\}$-potent if A satisfies $RA = A^{s+1}R$ where $R \in \mathbb{C}^{n\times n}$ is a fixed involutory matrix. Lately, many papers have appeared giving information about these matrices. In this talk, we present some recent results related to this kind of matrices. We stress on the spectral theory of $\{R, s+1\}$-potent matrices.

This is joint work with L. Lebtahi, J. Stuart and N. Thome. This work was partially supported by Ministerio de Economía y Competitividad (MTM2013-43678-P and Red de Excelencia MTM2015-68805-REDT).

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Hyponormality of block Toeplitz operators with circulant matrix function symbols

This talk focuses on hyponormality for Block Toeplitz operators with circulant matrix function symbols. In this talk, we establish a connection between hyponormality of Block Toeplitz operators with circulant matrix function symbols and hyponormality of (scalar) Toeplitz operators with induced symbols.

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Global Weyl modules for non standard maximal parabolics of twisted Affine lie algebras

In this talk we will discuss the structure of non standard maximal parabolics of twisted affine Lie algebras, global Weyl modules and the associated commutative associative algebra, $\mathbf{A}_\lambda$. Since the global Weyl modules associated with the standard maximal parabolics have found many applications the hope is that these non-standard maximal parabolics will lead to different, but equally interesting applications.

This is joint work under the guidance of my advisor, Vyjayanthi Chari.

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Numerical range techniques in quantum information science

We discuss numerical range techniques in quantum information science research. Recent results and problems will be mentioned.

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Principal eigenvectors and spectral radii of uniform hypergraphs

In this paper, some inequalities among the principal eigenvector, spectral radius and vertex degrees of a connected uniform hypergraph are established. Futhermore, we present some bounds on the spectral radius for a connected irregular uniform hypergraph in terms of some parameters, such as maximum degree, diameter and the number of vertices and edges.

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Sign patterns that allow diagonalizability

A sign pattern (matrix) is a matrix whose entries are from the set $\{+, -0\}$. A sign pattern $\mathcal{A}$ is said to allow diagonalizability if there is a diagonalizable real matrix whose entries have signs specified by the corresponding entries of $\mathcal{A}$. Characterization of sign patterns that allow diagonalizability has been a long standing open problem. In this talk, we review some known results on sign patterns that allow diagonalizability, and we further investigate necessary and/or sufficient conditions for a sign pattern to allow diagonalizability. In particular, it is shown that for every square sign pattern $\mathcal{A}$, there is a permutation sign pattern $\mathcal{P}$ such that $\mathcal{AP}$ allows diagonalizability.

This is joint work with Xinlei Feng, Guangming Jing, and Chris Zagrodny

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Monotonicity of certain maps of positive definite matrices

This talk is concerned with the monotonicity of $B^*G_n(A_1, \ldots, A_n)^{-1}B$ under the normalized completely positive map Φ from one C^*-algebra into another, where $A_1, \cdots, A_n$ are positive definite matrices, B is a positive semidefinite matrix, and G_n is the multi-variable geometric mean of $A_1, \cdots, A_n$ in the sense of Hansen, which is positively homogeneous regular and satisfies the properties of concavity and self-duality. We will report some recent developments in the study of the monotonicity. Moreover, we will present some equivalent forms of Lieb-Ruskai's convexity theorem.

This is joint work with Guanghua Shi (SJTU) and Ti-Jun Xiao (Fudan University). This work was supported by NSFC grant 11571229.

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Multiplicative Geometric Means

The weighted geometric mean $A\#_t B := A^{\frac{1}{2}}(A^{-\frac{1}{2}}BA^{-\frac{1}{2}})^t A^{\frac{1}{2}}$ of positive definite matrices appears as the unique (up to parametrization) geodesic line containing A and B in the Cartan-Hadamard Riemannian manifold of positive definite matrices equipped with the trace metric $\delta(A, B) = || \log A^{-1}B||_F$ and its multivariate or integrable measure extension is a currently active research topic in matrix analysis. In this talk we present a new construction of multivariate geometric means via the
following nonlinear matrix equation

$$\sum_{1\leq i,j\leq n} \log\left(X^{-\frac{1}{2}}(A_i\#_t A_j)X^{-\frac{1}{2}}\right) = 0.$$

This includes the Karcher equation at $t = 0$ or $t = 1$.

We show that it has a unique positive definite solution for $t \in [0, 1]$, denote by $\Lambda_{t,n}(A_1, \ldots, A_n)$, and gives rises to a new multivariate geometric mean of positive definite matrices with the *multiplicative property*; $\Lambda_{t,n}(A_1, \ldots, A_n) = \Lambda_{t,nk}(A_1, \ldots, A_n, \ldots, A_1, \ldots, A_n)$.

We discuss its unique extension to the setting of Borel probability measures with finite first moment on the Riemannian manifold and several inequalities including Ando-Hiai log-majorization and Yamazaki's inequality.

This talk is based on a joint work with Sejong Kim and Hosoo Lee.

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Note on von Neumann and Rényi entropies of a graph

Let G be a graph and L its combinatorial Laplacian matrix. The scaled Laplacian matrix $\frac{1}{\mathrm{tr(L)}}L$ is a positive semidefinite matrix with trace one, so it can be written as $\sum_{i=1}^{n} \lambda_i E_i$, where λ_i's are the eigenvalues and E_i's are rank-one matrices. Since $\lambda_i \geq 0$ and $\sum_{i=1}^{n} \lambda_i = 1$, such a matrix can be viewed as a mixture of several rank-one matrices and is called a density matrix in quantum information. The von Neumann entropy $\sum_{i=1}^{n} \lambda_i \log_2 \frac{1}{\lambda_i}$ and the Rényi α-entropy $\frac{1}{1-\alpha}\log_2(\sum_{i=1}^{n} \lambda_i^{\alpha})$ for $\alpha > 1$ measure the mixedness of a density matrix; in this talk, we will discuss how these entropies relate to different graphs.

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Fast joint blind deconvolution and demixing via nonconvex optimization

We study the question of reconstructing a sequence of functions $\{f_i, g_i\}_{i=1}^s$ from observing only the sum of their convolutions, i.e., from $y = \sum_{i=1}^s f_i * g_i$.

While convex optimization techniques are able to solve this joint blind deconvolution-demixing problem provably and robustly under certain conditions, for medium-size or large-size problems we need computationally faster methods without sacrificing the benefits of mathematical rigor that come with convex methods.

In this paper, we present a non-convex algorithm which guarantees exact recovery under conditions that are competitive with convex optimization methods, with the additional advantage of being computationally much more efficient. Our two-step algorithm converges to the global minimum linearly and is also robust in the presence of additive noise. While the derived performance bounds are suboptimal in terms of the information-theoretic limit, numerical simulations show remarkable performance even if the number of measurements is close to the number of degrees of freedom. We discuss an application of the proposed framework in wireless communications in connection with the Internet-of-Things.

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Eigenvalue crossings in Hermitian pencils and the boundary of the numerical range

A point on the boundary of the numerical range of a matrix A is multiply generated if it is the image of more than one linearly independent unit vector under the numerical range map $x \mapsto x^*Ax$. In this talk, we give an upper bound on the number of eigenvalue crossings in a Hermitian matrix pencil $H + tK$ with real parameter t. These results give new upper bounds on the possible number of isolated multiply generated boundary points of a numerical range. We will also discuss how these results relate to questions about the continuity properties of the inverse numerical range map.

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A new necessary condition for the spectrum of nonnegative symmetric 5×5 *matrices*

The Symmetric Nonnegative Inverse Eigenvalue Problem (SNIEP) asks when is a list $\sigma = (\lambda_1, \lambda_2, \ldots, \lambda_n)$ the spectrum of a nonnegative symmetric $n \times n$ matrix.

The problem is currently unsolved for any $n \geq 5$.

We consider in this talk the case $n = 5$, and assume $\lambda_1 \geq \lambda_2 \geq \lambda_3 \geq \lambda_4 \geq \lambda_5$. We show that if σ is the spectrum of a nonnegative symmetric 5×5 matrix and also satisfies $\sum_{i=1}^5 \lambda_i \geq \frac{1}{2}\lambda_1$, then $\lambda_3 \leq \sum_{i=1}^5 \lambda_i$. This establishes a new necessary condition for SNIEP in case $n = 5$, given by a linear inequality among the entries of

σ. It joins another necessary condition given by a linear inequality, due to McDonald and Neumann. Using the new condition SNIEP is solved for part of the region that has been unknown before for $n = 5$.

This talk is based on joint work with Oren Spector.

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Inverse Free Rational Krylov Subspaces for Computing Matrix Functions

Rational Krylov subspaces have been proven to be useful for many applications, like the approximation of matrix functions or the solution of matrix equations. It will be shown that extended and rational Krylov subspaces 'under some assumptions' can be retrieved without any explicit inversion or system solves involved. Instead we do the necessary computations of $A^{-1}v$ in an implicit way using the information from an enlarged standard Krylov subspace.

It is well-known that both for classical and extended Krylov spaces, direct unitary similarity transformations exist providing us the matrix of recurrences. In practice, however, for large dimensions computing time is saved by making use of iterative procedures to gradually gather the recurrences in a matrix. Unfortunately, for extended Krylov spaces one is required to frequently solve, in some way or another a system of equations. In this talk both techniques will be integrated. We start with an orthogonal basis of a standard Krylov subspace of dimension $k+m+p$. Then we will apply a unitary similarity built by rotations compressing thereby significantly the initial subspace and resulting in an orthogonal basis approximately spanning an extended or rational Krylov subspace.

Numerical experiments support our claims that this approximation is very good if the large Krylov subspace contains $A^{-m+1}v, \ldots, A^{-1}v$ and thus can culminate in nonneglectable dimensionality reduction and as such also can lead to time savings when approximating, e.g., matrix functions.

We show that our inverse-free method converges geometrically in the oversampling parameter p. We will present examples with Toeplitz matrices comparing the prediction from the theorem with numerical experiments.

This is joint work with Carl Jagels (Hanover College), Miroslav Pranic (Univeristy of Banja Luka), Lothar Reichen (Kent State University), and Raf Vandebril (KU Leuven).

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Majorization and Matrix Polynomials

Majorization of vectors in $\mathbb{R}^n$ (or $\mathbb{Z}^n$) is an important relation in many parts of linear algebra. It is the key element, for example, in the well-known Schur-Horn theorem, which characterizes the possible diagonals of Hermitian matrices having a given set of (real) eigenvalues. An analogous problem is to characterize the possible diagonals of upper triangular matrix polynomials that realize a given set of invariant factors. Such a characterization was given by Marques de Sa in 1980. In this talk we give an alternative characterization expressed in terms of majorization, and describe the elementary tools that can be used to prove this result. We also describe a natural extension to upper triangular rational realizations of a given Smith-McMillan form.

This is joint work with Luis Miguel Anguas-Marquez, Froilan Dopico, and Richard Hollister.

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On The Asymptotic Performance of ℓ_q-regularized Least Squares

In many application areas ranging from bioinformatics to imaging we are faced with the following question: Can we recover a p-dimensional sparse vector β from its n, $(n < p)$ noisy observations $y = X\beta + \epsilon$. The last decade has witnessed a surge of algorithms to address this question. One of the most popular algorithms is the ℓ_q-regularized least squares given by the following formulation:

$\hat{\beta}(\lambda, q) = \arg\min_{\beta} \frac{1}{2}\|y - X\beta\|_2^2 + \lambda\|\beta\|_q^q$,

where $0 \leq q \leq 2$. Despite the non-convexity of these optimization problems for $0 < q < 1$, they are still appealing for their closer proximity to the 'ideal' ℓ_0-regularized least squares. In this talk, we adopt the asymptotic framework $p \to \infty$ and $n/p \to \delta$ and analyze the properties of the global minimizer of LQLS under the optimal tuning of the parameter λ. Our goal is to answer the following questions: (i) Do non-convex regularizers outperform convex regularizers? (ii) Does $q = 1$ outperform other convex optimization problems when the vector β_o is sparse?

We discuss both the predictive power and variable selection accuracy of these algorithms. If time permits, we also discuss algorithms that can provably reach to the global minima of the non-convex problems in certain regimes.

This talk is based on a joint work with Haolei Weng, Shuaiwen Wang, and Le Zheng.

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Merging in bipartite distance-regular graphs

Merging the first and third classes in a connected graph is joining all the pairs of vertices with distance 1 or 3 in the graph with edges. We determine when merging the first and third classes in a bipartite distance-regular graph produces a distance-regular graph.

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A Kaczmarz Method for Low Rank Matrix Recovery

The Kaczmarz method was initially proposed as a row-based technique for reconstructing signals by finding the solutions to overdetermined linear systems. We propose a weighted Kaczmarz method that can recover low rank matrices from linear measurements both in the overdetermined and underdetermined regimes.

This is joint work with Ulugbek Kamilov and Ozgur Yilmaz.

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Extended spectral equivalence

Spectral equivalence is defined in the set of matrix polynomials with certain size conditions. In this talk we extend this equivalence relation in two ways. First, we do not impose any restriction on the size, rank or degree of the matrix polynomials and show that the finite and infinite elementary divisors form a complete set of invariants for it. Then we characterize this equivalence relation in terms of coprimeness, that is, we give a coprimeness criterion of when two matrix polynomials have the same finite and infinite elementary divisors. Secondly, we extend spectral equivalence to the set of rational matrices. Like in the polynomial case, this allows us to characterize strong linearizations of rational matrices by using spectral equivalence.

This is joint work with A. Amparan and I. Zaballa. This work is supported by Ministerio de Economía y Competitividad of Spain through grants MTM2013-40960-P and MTM2015-68805-REDT and by the University of the Basque Country UPV/EHU through grants GIU16/42 and UFI11/52.

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On Symmetric Nonnegative Realizability

The first known sufficient condition for the Symmetric Nonnegative Inverse Eigenvalue Problem (SNIEP) is due to Perfect-Mirsky in 1965 in the context of doubly stochastic matrices. Then Fiedler in 1974 gave the first one for symmetric nonnegative matrices. Since then several and diverse sufficient conditions have contributed to the understanding of this intriguing problem. Marijuán-Pisonero-Soto have established inclusion relations or independency relations between them. Recently, Ellard-Smigoc described a recursive method of constructing symmetrically realizable spectra and showed the equivalence with some of the strongest known sufficient conditions for the SNIEP.

We present a sufficient condition for the SNIEP in terms of majorization of partitioned sums of the negative eigenvalues by a selection of positive eigenvalues. This sufficient condition includes Suleimanova and Loewy results for one and two positive eigenvalues, respectively. We set out some examples to show the scope and the limitations of this condition.

This work is based on a joint paper with C.R. Johnson and M. Pisonero.

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The signed epr-sequence

The *principal minor assignment problem* asks the following question: Can we find an $n \times n$ matrix having prescribed principal minors? As a simplification of this problem, researchers associated a sequence with a symmetric (or complex Hermitian) matrix, which they defined as follows: The *enhanced principal rank characteristic sequence* (*epr-sequence*) of an $n \times n$ symmetric (or complex Hermitian) matrix B is $\ell_1\ell_2 \cdots \ell_n$, where
ℓ_k is $\mathtt{A}$ (respectively, $\mathtt{N}$) if all (respectively, none) of the principal minors of order k are nonzero;
if some but not all are nonzero, then $\ell_k = \mathtt{S}$.

As a refinement of the epr-sequence, the present author recently introduced the *signed enhanced principal rank characteristic sequence* (*sepr-sequence*) of an $n \times n$ Hermitian matrix, denoted $t_1t_2 \cdots t_n$, where
t_k is either $\mathtt{A}^*$, $\mathtt{A}^+$, $\mathtt{A}^-$, $\mathtt{N}$, $\mathtt{S}^*$, $\mathtt{S}^+$, or $\mathtt{S}^-$, based on the following criteria:
$t_k = \mathtt{A}^*$ if B has both a positive and a negative order-k principal minor, and
each order-k principal minor is nonzero;
$t_k = \mathtt{A}^+$ (respectively, $t_k = \mathtt{A}^-$) if each order-k principal minor is positive (respectively, negative);
$t_k = \mathtt{N}$ if each order-k principal minor is zero;
$t_k = \mathtt{S}^*$ if B has each a positive, a negative, and a zero order-k principal minor;
$t_k = \mathtt{S}^+$ (respectively, $t_k = \mathtt{S}^-$) if B has both a zero and a nonzero order-k principal minor, and
each nonzero order-k principal minor is positive (respectively, negative).

In this talk, results regarding the attainability of epr- and sepr-sequences are discussed. In particular, results forbidding certain subsequences from appearing in the sepr-sequence of a Hermitian matrix are presented. The notion of a *nonnegative* and *nonpositive* subsequence is introduced, which leads to a connection with positive semidefinite matrices.

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Matrix convex sets defined by non-commutative polynomials

For positive integers g and h, let x and y denote g and h tuples of freely non-commuting variables respectively. A (non-commutative) polynomial $p(x, y)$ is naturally evaluated as $p(X, Y)$ at a pair (X, Y), where X is a g-tuple and Y is an h-tuple of symmetric matrices all of the same size. The polynomial p is symmetric if $p(X, Y)^T = p(X, Y)$ for all such (X, Y). In the case p is symmetric, the positivity set of p at X consists of those Y such that $p(X, Y)$ is positive definite. The polynomial p is convex with respect to a set S of tuples X if the positivity set of p at X is convex for each X in S. This talk will survey structure theorems for polynomials and their associated positivity sets under the assumption that p is convex with respect to various choices of S. It may include a brief discussion of systems engineering motivations.

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Spectrally Arbitrary Patterns over Different Fields

An $n \times n$ pattern is said to be spectrally arbitrary over a field F provided any n-th degree monic polynomial over F can be realized by a matrix with the given pattern and entries from F. In this talk we will look at algebraic and analytic properties of fields and illustrate how these properties can help us predict whether or not a pattern that is spectrally arbitrary over one field will be spectrally arbitrary over a subfield or field extension.

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Subspace Procedures for Large-Scale Stability Radius Problems

Consideration of the robust asymptotic stability of a dynamical system is essential in the presence of uncertainty. Computation of stability radius, a standard measure for robust stability, for large-scale dynamical systems still stands as a major challenge. We propose subspace procedures to deal with large dimensionality of several stability radius problems. The talk starts by introducing general subspace frameworks for eigenvalue and singular value optimization problems, together with their theoretical convergence properties. The second part discusses how these general frameworks can be adopted specifically for unstructured complex stability radius. The talk concludes with the extensions of the subspace procedures for structured stability radius problems with multiplicative structure, and, if time permits, for structured stability radius problems arising from dissipative Hamiltonian systems. With the proposed subspace procedures, it is usually possible to compute stability radius to a high accuracy for sparse dynamical systems with orders tens of thousands.

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Z sharp forcing

Given a simple graph G, the usual version of the zero forcing game obtains a combinatorial upper bound for the maximum multiplicity of an eigenvalue of any symmetric matrix whose off-diagonal zero nonzero pattern agrees with the adjacency matrix of G. In this talk, a new version of the zero forcing game, $Z_{\#}(G, t)$, will be defined. This game extracts additional combinatorial information about the maximum multiplicities of the eigenvalues of such a matrix by considering 'partial' zero forcing sets with t forcing chains (where $t \leq Z(G)$) and interpreting them in terms of the underlying linear algebra.

This is joint work with D. Ferrero, M. Flagg, H. T. Hall, L. Hogben, C.-H. Lin, S. Nasserasr, and B. Shader. This work was begun at the AIM workshop - Zero Forcing and its Applications in Jan. 2017.

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A technique to approximate the probability of partial extinction events in metapopulations.

An important statistic in stochastic epidemic modeling is the probability of total disease extinction, $\mathbb{P}_0$. While it is often difficult to solve a continuous time Markov chain (CTMC) for $\mathbb{P}_0$, it has been successfully approximated using branching process techniques in both single population and metapopulation models. Certain assumptions must hold to guarantee the accuracy of branching process approximation. However, these assumptions may not hold in some cases. The structure of such models is characterized by the migration matrix, which consists of rates of movement between subpopulations or patches. Extinction in a single patch of a metapopulation is transient event, which branching process techniques are not suited to calculate. Partial extinction events are described mathematically and the value of approximating the likelihood of specific partial extinction events is discussed. The probability of extinction is the probability of hitting a subspace of the state space. A new technique for approximating hitting probabilities, called Local Approximation in Time and Space (LATS), is presented. LATS is shown to be universally applicable to hitting problems in Markov chains and specifically applicable to calculating extinction probabilities. It is often the case that stochastic metapopulation models of disease can be represented by a discrete Markov chain on a lattice with nearest neighbor transitions. LATS is shown to be particularly useful in this case.

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Spectra of the generalized subdivision and other extensions of a network

The aim of these work is to investigate the connection between the eigenvalues and eigenfunctions of a network $\Gamma = (V, E, c)$ and those of its generalized subdivision network $\Gamma' = (V \cup V', E', c')$. This is the network obtained from Γ by adding a new vertex in some of its edges. Our interest lies in interpreting the matrix associated with a Schrödinger operator of Γ as the Schur complementation of a suitable Schrödinger operator on Γ with respect to a set of vertices. This process is known in circuit theory and releted areas as Kron reduction.The spectrum of some networks obtained as extension from Γ will be analized.

This is joint work with À. Carmona and A.M. Encinas.
This work has been partially supported by the Programa Estatal I+D+i of MINECO, Spain, under the project MTM2014-60450-R.

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Explicit Restricted Isometries

A fundamental open problem in compressed sensing is to explicitly construct matrices that satisfy the restricted isometry property. Work on this problem has leveraged ideas from various fields including additive combinatorics, number theory, representation theory, and combinatorial design. This talk will survey the state of the art and discuss recent developments.

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Order automorphisms in matrix algebras and in operator algebras and their applications

We consider two types of partial orderings on selfadjoint elements in the full operator algebra over a Hilbert space. The usual one coming from the notion of positive semidefiniteness and the so-called spectral order. We first describe and discuss the corresponding (non-linear) automorphisms of those partially ordered sets. Next we present applications concerning the structures of maps preserving certain divergences, kinds of relative entropies on positive definite matrices and isometries on positive semidefinite operators. Finally, we give characterizations of certain operations on the positive definite cone.

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Green's kernel of Schrödinger operators on generalized subdivision networks

In this work we calculate Green's kernel of positive semi-definite Schrödinger operators on generalized subdivision networks in terms of the corresponding Green's kernel of a Schrödinger operator on the original network. As a by-product we also obtain the effective resistances and the Kirchhoff index of generalised subdivision networks.

A generalized subdivision network $\Gamma' = (V', E', c')$ of a given network $\Gamma = (V, E, c)$ is obtained by adding a new vertex v_{xy} at some (not necessarily all) edges $\{x, y\} \in E$ and by defining new conductances $c(x, v_{xy})$ so as to satisfy a kind of an *electrical compatibility* condition.

In this setting we prove how the solution of a compatible Poisson problem on the generalized subdivision network Γ' is related with the solution of a suitable Poisson problem on the initial network Γ. We use appropriate contraction and extension of functions and operators to achieve our result.

As Green's function with pole on a given vertex is calculated from a particular solution of a Poisson problem, we can establish an affine relationship between Green's kernel defined for vertices in Γ' and the one defined on Γ. We take advantage of this relation not only with the evaluation of effective resistances but also with the Kirchhoff index.

This is a joint work with Ángeles Carmona and Margarida Mitjana, Universitat Politècnica de Catalunya, BarcelonaTech, Spain.

This work has been partially supported by the Programa Estatal de I+D+i del Ministerio de Economía y Competitividad, Spain, under the project MTM2014-60450-R.

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On the sum of strictly k-zero matrices

Let k be an integer such that $k \geq 2$. An n-by-n matrix A is said to be strictly k-zero if $A^k = 0$ and $A^m \neq 0$ for all positive integers m with $m < k$. Suppose A is an n-by-n matrix over a field with at least three elements. We show that if A is a nonscalar matrix with zero trace, then i) A is a sum of four strictly k-zero matrices for all $k \in \{2, \ldots, n\}$; and ii) A is a sum of three strictly k-zero matrices for some $k \in \{2, \ldots, n\}$. We prove that if A is a scalar matrix with zero trace, then A is a sum of five strictly k-zero matrices for all $k \in \{2, \ldots, n\}$. We also determine the least positive integer m such that every square complex matrix A with zero trace is a sum of m strictly k-zero matrices for all $k \in \{2, \ldots, n\}$.

This is a joint work with Professor Agnes T. Paras of the University of the Philippines Diliman.

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Contour integral methods for rectangular eigenproblems

Consider solving rectangular eigenproblems for the eigenvalues inside a prescribed region in the complex plane and the corresponding eigenvectors. It is shown that the eigenpairs are computed by using contour integrals under a certain condition. One of the methods reduces the problem to the eigenproblem of a Hankel matrix pencil, and the other takes a Rayleigh-Ritz-like procedure. Numerical experiments show that the methods give the desired eigenpair.

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Local reduction of Hermitian eigenproblems

We consider the reduction of linear systems and eigenproblems involving Hermitian matrices with known and unknown blocks. Limited knowledge of a matrix limits our ability to reduce the size of a problem. For linear systems, we can perform a partial Gaussian elimination with limited knowledge. For eigenproblems, we can only perform a useful reduction if we focus on a limited range of eigenvalues. We analyze the tradeoffs between cost, accuracy, and range of applicability. These results serve as a foundation for spectral divide-and-conquer methods for eigenproblems, complementary to established partition-based divide-and-conquer methods. We outline an application to banded matrices, where the eigenvalues and structured eigenvectors of an n-by-n matrix of bandwidth b can be computed in $O(b^2 n \log n)$ operations.

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Graded Representations of Current Algebras

One motivation for studying graded representations of current algebras is the desire to understand irreducible representations for the quantum affine Lie algebras. In this talk, I will focus on the graded representations of the current algebra associated to a partition ξ, called $V(\xi)$, which were first defined by Chari and Venkatesh. In particular, I will explain what we know about the structure of these representations.

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Singular points of the Kippenhahn curves for unitary bordering matrices

For an $n \times n$ complex matrix A, the Kippenhan curve is the set of zeros of the form $\det(x\Re(A) + y\Im(A) + zI_n)$ in the complex projective plane. An $n \times n$ matrix is called 'unitary bordering' if $I_n - A^*A$ is a rank one positive Hermitian matrix and the modulus of every eigenvalueof A is strictly less than 1. The author shows that every singular point of the Kippenhahn curve for a unitary bordering matrix does not exist in the real projective plane. This talk is based on the joint work of Professor Mao-Ting Chien.

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Distinct eigenvalues of graphs

Let G be a simple graph on n vertices. The set of real symmetric $n \times n$ matrices with nonzero off-diagonal entries in exactly the positions corresponding the ones in the adjacency matrix of G is denoted by $S(G)$. Eigenvalues of the matrices in $S(G)$ have been studied extensively in the area of inverse eigenvalue problems. The minimum number of distinct eigenvalues of a matrix in $S(G)$ (with respect to a fixed integer n), is denoted by $q(G)$. We survey some results about the parameter $q(G)$, including characterizations of graphs for which the value of $q(G)$ is known.

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Matrices whose hermitian part is positive semidefinite.

Matrices whose hermitian part is positive definite have been well studied. Let $A \in \mathbb{C}^{n\times n}$. Denote the real part of A by $H_A = \frac{1}{2}(A + A^*)$ and the imaginary part by $K_A = \frac{1}{2i}(A - A^*)$.
(1) If H_A is positive definite, then $A^{-1}A^*$ and A^*A^{-1} are similar to unitary matrices.
(2) Let H_A is positive definite and define $M = maxRe(\lambda(A^{-1}A^*)$ and $m = minRe(\lambda(A^{-1}A^*)$. Then
(i) $\beta H_{A^{-1}} - H_A^{-1}$ is positive semidefinite if and only if $\beta \geq 2/(m + 1)$, and
(ii) $\eta H_A^{-1} - H_{A^{-1}}$ is positive semidefinite if and only if $\eta \geq (M + 1)/2$.
In this talk we shall extend these two results for matrices whose hermitian part is positive semidefinite using the notion of the Moore-Penrose inverse. We also present some other related results for this class of matrices.
This is joint work with K.C. Sivakumar.

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An equivalence between local state discrimination and state transformation in multipartite systems

It is well-known that some sets of orthogonal quantum states cannot be perfectly (or even unambiguously) distinguished using only local operations and classical communication (LOCC) and, in fact, a complete basis cannot be perfectly distinguished if it contains any entangled states. This challenge can sometimes be overcome in the presence of additional shared entanglement. For instance, any maximally-entangled bipartite state enables quantum teleportation, which in turn allows any complete global measurement to be implemented.

We show a related equivalence between the problems of local state discrimination and local state transformation; and demonstrate connections to related algebraic questions. When we apply this characterization to multipartite systems, we see that in general there is no entangled state from the same space that can enable all measurements by LOCC.

This is based on joint work with Bandyopadhyay and Halder.

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Teaching combinatorial convexity applications in an undergraduate linear algebra class.

Linear Algebra (LA) is an important tool in Combinatorial Convexity Theory (CCT). In this talk we review simple concepts and results from CCT that can be used to increase the students understanding of basic LA ideas. Caratheodory's Theorem and Radon's Theorem constitute nice applications (within Mathematics) that can be proved in an introductory LA class. Moreover, these theorems (and to some extent Tverberg's and Helly's Theorems) can be used as a source of exercises whose solution require only the use of introductory-level LA concepts (e.g., linear dependency, column space, null space, dimension, etc.)

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Backwards Stability of the Schur Canonical Form

Previous results in the literature explored the forward stability of various matrix canonical forms under small perturbations. Here we consider the extension of such a result to the Schur form. Based off of similar results in the literature, we considered the following theorem as a possibility.

Let $A_0 = U_0 T_0 U_0^*$ where U_0 is unitary and T_0 is upper triangular. Then, there exists constants $K, \epsilon > 0$ (depending on A_0 only) such that for all A such that $||A - A_0|| < \epsilon$ there exists U, T such that $A = UTU^*$ such that

$$||U - U_0|| + ||T - T_0|| \leq K||A - A_0||^{1/n} \tag{3}$$

Above, the bound is called Hölder and the $1/n = 1$ instead, it is called Lipschitz. In the paper, we conclude that the above result does not hold in general. However, we conclude that backwards stability can be achieved for the Schur form. Through the use of gap and semi-gap theory, we prove the following.

Let A_0 be given. Then, there exists constants $K, \epsilon > 0$ (depending on A_0 only) such that for all A such that $||A - A_0|| < \epsilon$ the following holds. For every U, T (U unitary) such that $A = TU^*$ there exists U_0, T_0 such that $A_0 = U_0 T_0 U_0^*$ and

$$||U - U_0|| + ||T - T_0|| \leq K||A - A_0||^{1/n} \tag{4}$$

This is a joint work with V. Olshevsky.

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Low Rank Matrix Completion and Beyond

Low rank matrix completion (LRMC) refers to imputing unknown missing entries in a low rank matrix. This is equivalent to solving a system of polynomial equations, and this perspective sheds light on the problem and its generalizations. This talk will cover LRMC from an algebraic perspective and discuss extensions to completing matrices that are not low rank, but have other more general algebraic structure.

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The second largest eigenvalue and vertex-connectivity in regular graphs

In this talk, for a fixed positive integer d at least 3, we study upper bounds for the second largest eigenvalue in (an n-vertex) d-regular graph to guarantee a certain vertex-connectivity.

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The maximum of the minimal multiplicity of eigenvalues of symmetric matrices whose pattern is constrained by a graph

In this talk, we introduce a parameter $\mathrm{Mm}(G)$, defined as the maximum over the minimal multiplicities of eigenvalues among all symmetric matrices corresponding to a graph G.

The parameter Mm brings a new point of view to the study of the Inverse Eigenvalue Problem for graphs. In contrast to other parameters (e.g. $\mathrm{mr}(G)$, $q(G)$,...) connected with this problem, Mm is distinguished by the fact that it forces one to look at multiplicities of all the eigenvalues of a matrix. Matrices that achieve $\mathrm{Mm}(G)$ for a given graph G are in some sense as far as possible from the generic case.

We will present basic properties of $\mathrm{Mm}(G)$ and compute it for several families of graphs.

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On the Computation of a Truncated SVD of a Large Linear Discrete Ill-Posed Problem

The singular value decomposition is commonly used to solve linear discrete ill-posed problems of small to moderate size. This decomposition not only can be applied to determine an approximate solution, but also provides insight into properties of the problem. However, large-scale problems generally are not solved with the aid of the singular value decomposition, because its computation is considered too expensive. This talk shows that a truncated singular value decomposition, made up of a few of the largest singular values and associated right and left singular vectors, of the matrix of a large-scale linear discrete ill-posed problems can be computed quite inexpensively by an implicitly restarted Golub-Kahan bidiagonalization method. Similarly, for large symmetric discrete ill-posed problems a truncated eigendecomposition can be computed inexpensively by an implicitly restarted symmetric Lanczos method.

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Connections between preserver problems, graph theory, and finite geometry

A typical preserver problem in matrix theory demands a characterization of all maps $\Phi : \mathcal{M} \to \mathcal{M}$ on a set that consists of some matrices, which preserve a certain given function, subset, relation, etc. Preservers of some binary relations turn out to be very important in this research area. These can be interpreted also as graph endomorphisms of an appropriate graph. The existence of a graph homomorphism between two graphs is tightly related to various graph invariants such as the clique number, the independence number, the chromatic number, the Lovász theta function, etc. All these numbers are related to graph spectrum. In the talk I will survey certain techniques from spectral graph theory that can be applied to solve certain preserver problems. I will also point to an increasing number of examples, which show that there is an important overlapping in the research of preserver problems, the study of graph homomorphisms, and certain subareas in finite geometry.

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The numerical range as a spectral set

It is shown that the numerical range of a linear operator on a Hilbert space is a $(1+\sqrt{2})$-spectral set. The proof relies, among other things, on the behavior of the Cauchy transform of the conjugates of holomorphic functions.

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On the recent advances in the multivariable theory of operator monotone functions and means

The origins of this talk go back to the fundamental theorem of Loewner in 1934 on operator monotone real functions and also to the hyperbolic geometry of positive matrices. Loewner's theorem characterizing one variable operator monotone functions has been very influential in matrix analysis and operator theory. Among others it lead to the Kubo-Ando theory of two-variable operator means of positive operators in 1980.

One of the nontrivial means of the Kubo-Ando theory is the non-commutative generalization of the geometric mean which is intimately related to the hyperbolic, non-positively curved Riemannian structure of positive matrices. This geometry provides a key tool to define multivariable generalizations of two-variable operator means. Arguably the most important example of them all is the Karcher mean which is the center of mass on this manifold. This formulation enables us to define this mean for probability meaures on the cone of positive definite matrices extending further the multivariable case. Even the infinite dimensional case of positive operators is tractable by abandoning the Riemannian structure in favor of a Banach-Finsler structure provided by Thompson's part metric on the cone of positive definite operators. This metric enables us to develop a general theory of means of probability measures defined as unique solutions of nonlinear operator equations on the cone, with the help of contractive semigroups of nonlinear operators. The order preserving property of operator means and operator monotone functions are crucial in this theory.

We also introduce the recently established structure theory of multivariable operator monotone functions extending the classical result of Loewner into the non-commutative multivariable realm of free functions, providing theoretically explicit closed formulas for our multivariable operator means.

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A matricial view of the Karpelevič Theorem

The question of the exact region in the complex plane of the possible single eigenvalues of all n-by-n stochastic matrices was raised by Kolmogorov in 1937 and settled by Karpelevič in 1951 after a partial result by Dmitriev and Dynkin in 1946. The Karpelevič result is unwieldy, but a simplification was given by Doković in 1990 and Ito in 1997. The Karpelevič region is determined by a set of boundary arcs each connecting consecutive roots of unity of order less than n.

However, noticeably absent in the Karpelevič theorem (and the above-mentioned works) are *realizing-matrices* (i.e., a matrix whose spectrum contains a given point) for points on these arcs. In this talk we show that each of these arcs is realized by a single, somewhat simple, parameterized stochastic matrix. Other observations are made about the nature of the arcs and several further questions are raised. The doubly stochastic analog of the Karpelevič region remains open, but a conjecture about it is amplified.

This is joint work with Charles R. Johnson.

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Numerical ranges with rotational symmetry

If A is an $n \times n$ matrix with $a_{ij} = 0$ unless either $i = j + 1$ or both $i = 1$ and $j = n$, then $W(A)$ has n-fold symmetry about the origin. The numerical ranges of these matrices and their adjoints have been studied extensively. For instance, Li and Tsing (1994) showed that block matrices of this form are exactly the operators where the C-numerical ranges all have n-fold symmetry about the origin. Results also appear in papers by Tam and Yang (1999) and Tsai and Wu (2011). Some settings where these matrices arise will be discussed, as will numerical range properties of generalizations of this class of matrices.

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Quantum Chromatic Numbers

The chromatic number of a graph can be characterized as the minimal c for which a perfect deterministic strategy exists for a game called the c-coloring game. If instead of giving deterministic the players use classical random variables to produce their answers then the least c for which the players can win the c-coloring game with probability one is still the chromatic number.

However, if they are allowed to use the random outcomes of entangled quantum experiments to produce their answers, then the players can win the c-coloring game with probability one for values of c that are much smaller than the chromatic number. The least c for which one can win this game using such quantum probabilities is called the quantum chromatic number of the graph. Computing this integer reduces to finding systems of projection matrices that satisfy certain combinatorial identities.

Also, there are several possible models for the set of quantum probability densities, whether these are all the same or different is related to conjectures of Connes and Tsirelson. These different models lead to several possible variants of the quantum chromatic number.

In this talk, I will introduce these ideas and introduce a free algebra whose representation theory determines the values of these chromatic numbers.

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On the Rank of Bipartite States with Prescribed Reduced States

Given an $m \times m$ density matrix ρ_1 and an $n \times n$ density ρ_2, we define $S(\rho_1, \rho_2)$ to be the set of all $mn \times mn$ density matrices ρ satisfying

$$\mathrm{tr}_1(\rho) = \rho_2 \text{ and } \mathrm{tr}_2(\rho) = \rho_1.$$

That is, $S(\rho_1, \rho_2)$ is the set of all quantum states of bipartite systems $X = (X_1, X_2)$ having reduced states on its two substituent components X_1, X_2 given by ρ_1 and ρ_2, respectively. In particular, the product state $\rho_1 \otimes \rho_2 \in S(\rho_1, \rho_2)$.

It is easy to show that if $\rho \in S(\rho_1, \rho_2)$, then

$$\max\left\{\left\lceil \frac{\mathrm{rank}(\rho_1)}{\mathrm{rank}(\rho_2)} \right\rceil, \left\lceil \frac{\mathrm{rank}(\rho_2)}{\mathrm{rank}(\rho_1)} \right\rceil\right\} \leq \mathrm{rank}(\rho) \leq \mathrm{rank}(\rho_1) \cdot \mathrm{rank}(\rho_2).$$

Moreover, for any given pair ρ_1, ρ_2, the upper bound given above is always attained by $\rho = \rho_1 \otimes \rho_2$. However, the lower bound is not always attained. In this talk, we discuss the conditions on the eigenvalues of ρ_1, ρ_2 that will guarantee the existence of a rank r element $\rho \in S(\rho_1, \rho_2)$.

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The Classical Mathematics Behind Some Concepts in Quantum Information

We explore some connections between some classical results and ideas in pure mathematics and some concepts in quantum information. We will show a relationship between the Bures angle in quantum information and the canonical angles between subspaces. We show how the answer to a Putnam competition problem on Hadamard matrices can be used to find the order of all maximal Abelian subgroups of tensor products of the Pauli matrices. We show how a result of Klein on invariant polynomials can be used to find symmetric spin states with high entanglement.

Parts of this talk are joint work with one of more of: C. Paul-Paddock, J.Li, S. Plosker, J. Levick, T. Jochym-O'Connor, D.W. Kribs and R. Laflamme.

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Structured backward error analyses of linearized polynomial eigenvalue problems

A matrix polynomial is structured if there are algebraic properties of its coefficients that induce some symmetries in its spectrum. Some of the most common of these algebraic structures that appear in applications are the (skew-)symmetric, (anti')palindromic, and alternating structures. The preferred method for solving a polynomial eigenvalue problem associated with a structured matrix polynomial starts by embedding the matrix polynomial in a larger matrix pencil preserving the structure of the original polynomial. The linearized problem can be solved by using well-understood structure-preserving algorithms such as the palindromic-QR algorithm. These algorithms are structurally global backward stable, which means that the computed spectrum is the exact one of a nearby structured matrix pencil. The goal of this talk is to present a novel approach to studying whether or not the computed spectrum of the linearized problem is the exact one of a nearby structured matrix polynomial, or, in other words, to study the backward stability of solving structured polynomial eigenvalue problems by structure-preserving linearization. To do so, we need to examine how generic structured perturbations of the linearized problem can be mapped onto structured perturbations of the coefficients of the original matrix polynomial. Our approach allows us to prove backward error results for a huge class of structure-preserving linearizations, provides precise bounds, and takes into account the structure that the matrix polynomial might possess.

This is joint work with F. M. Dopico, and P. Van Dooren.

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T-even Nonlinear Eigenvalue Problems and Structure-Preserving Interpolation

The nonlinear eigenvalue problem is to find scalars λ (eigenvalues) and nonzero vectors x (eigenvectors) satisfying $N(\lambda)x = 0$, where $N : \mathbb{C} \to \mathbb{C}^{n\times n}$. A convenient way of representing $N(\lambda)$ is

$$N(\lambda) \;=\; \sum_{i=0}^{k} f_i(\lambda)\, A_i\,, \tag{5}$$

where the $f_i : \mathbb{C} \to \mathbb{C}$ are nonlinear functions and $A_i \in \mathbb{C}^{n\times n}$.

A popular approach for solving nonlinear eigenvalue problems is to approximate $N(\lambda)$ by a matrix polynomial of the form

$$Q_k(\lambda) \;=\; b_0(\lambda)D_0 + b_1(\lambda)D_1 + \cdots + b_k(\lambda)D_k\,,$$

where D_j are $n \times n$ matrices and b_j are polynomials in λ. The associated polynomial eigenvalue problem $Q_k(\lambda)x = 0$ can then be solved by converting it into a larger but spectrally equivalent generalized eigenproblem $L(\lambda)z = 0$; such an $L(\lambda) = \lambda X + Y$ is called a *linearization* for $Q_k(\lambda)$.

Matrix functions $N(\lambda)$ arising in applications often have additional structure which translates into $N(\lambda)$ having some kind of eigenvalue pairing. Thus when computing eigenvalues of $N(\lambda)$ it is desirable to employ methods which would guarantee the computed eigenvalues have the same pairing. In this talk we consider the case when $N^T(-\lambda) = N(\lambda)$ and refer to the associated nonlinear eigenvalue problem as T*-even*. An example of such $N(\lambda)$ arising from delay differential equations is

$$N(\lambda) \;=\; \lambda^2 A + \lambda B + C + D_1 e^{\tau\lambda} + D_1^T e^{-\tau\lambda} + D_2 \lambda e^{\tau\lambda} - D_2^T \lambda e^{-\tau\lambda}\,, \tag{6}$$

where $A^T = A$, $B^T = -B$, and $C^T = C$. We show for which choices of nodes $N(\lambda)$ can be interpolated by a matrix polynomial $P(\lambda)$ so that both $N(\lambda)$ and $P(\lambda)$ are T-even. This structure-preserving interpolation process then guarantees that the eigenvalues of $N(\lambda)$ and $P(\lambda)$ have the same eigenvalue pairing. An interesting feature about the interpolating polynomial is that $P(\lambda)$ is expressed in a Lagrange basis. We show how to exploit this nonstandard representation to construct a new T-even linearization of $P(\lambda)$ without any conversion to the standard basis. Our construction is based on extending the concept of generalized Fiedler pencils to matrix polynomials expressed in Lagrange basis.

This is joint work with D. Steven Mackey.

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LIGHTS OUT! on Cartesian Products

The game *LIGHTS OUT!* is played on a 5×5 square grid of buttons; each button may be on or off. Pressing a button changes the on/off state of the light of the button pressed and of all its vertical and horizontal neighbors. Given an initial configuration of buttons that are on, the object of the game is to turn all the lights out. The game can be generalized to arbitrary graphs. We investigate graphs of the form $G\Box H$, where G and H are arbitrary finite, simple graphs. In particular, we provide conditions for which $G\Box H$ is universally solvable (every initial configuration of lights can be turned out by a finite sequence of button presses) using both closed neighborhood switching and open neighborhood switching.

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5-Spectra of Symmetric Nonnegative Matrices

For a long time it was thought that the real nonnegative inverse eigenvalue problem and the Symmetric Nonnegative Inverse Eigenvalue Problem (SNIEP) were equivalent, but in 1996 Johnson-Laffey-Loewy set lout that both problems are different and in 2004 Egleston-Lenker-Narayan proved that they are different for spectra of size greater than or equal to 5. Spectra of size 5 for the SNIEP are not characterized and this problem has proven a very challenging one. In 2011 Spector solved the trace zero case. Loewy-McDonald and Egleston-Lenker-Narayan in their works study the positive trace case. Recently, Loewy-Spector characterize 5-spectra symmetrically realizable that have trace greater than or equal to half of the Perron root.

It is common to study 5-spectra considering the number of positive eigenvalues. When there are 1, 4 or 5 positive eigenvalues the answer for the SNIEP is straightforward. We note that in all cases with 2 positive eigenvalues may be resolved. We give a new method, based upon the eigenvalue interlacing inequalities for symmetric matrices, to rule out many unresolved spectra with 3 positive eigenvalues. In particular, this new method shows that the nonnegative realizable spectrum $\{6, 3, 3, -5, -5\}$ is not symmetrically realizable.

This work is based on a joint paper with C.R. Johnson and C. Marijuán.

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Quantum state transfer via Hadamard diagonalizable graphs

Quantum state transfer within a quantum computer can be modeled mathematically by a graph. From the graph, we can then focus on the corresponding Adjacency matrix or Laplacian matrix; here, we are interested in the Laplacian matrix and those graphs for which the Laplacian can be diagonalized by a Hadamard matrix. We produce a wide variety of new graphs that exhibit either perfect or pretty good state transfer.

This is joint work with Nathaniel Johnston, Steve Kirkland, Rebecca Storey, and Xiaohong Zhang. This work was supported by NSERC Discovery Grant number 1174582.

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Elimination for nonlinear ODEs arising in biology

The following problems arise in modelling biological processes using ordinary differential (or difference) equations:

1. Eliminate (if possible) un-observable unknowns and obtain equations in the rest of the unknowns.

2. Express the parameters of the system (if possible) in terms of the observable unknowns and their derivatives.

We will discuss recent algorithms for solving these problems and illustrate them using systems arising in biological modelling (for example, for HIV-models).

This is joint work with Alexey Ovchinnikov.

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Measurement-Induced Nonlocality of Gaussian version

Measurement-induced nonlocality (MIN) for finite dimensional systems is introduced by Luo and Fu in [Phys. Rev. Lett., 106, 120401 (2011)], and Hou and Guo generalized MIN to infinite dimensional systems in [J. Phys. A: Math. Theor., 46, 325301 (2013)]. In this paper, we give the Gaussian version of MIN with von Neumann measurenment, and obtain an analytic formula of MIN for two-mode squeezed thermal states and mixed thermal states. Different from Gaussian quantum discord, we show that in the definition of the Gaussian version of MIN, the von Neumann measurenment cannot be replaced by Gaussian positive operator valued measurement.

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Counting matrices over finite fields

The *stable rank* of a $n \times n$ matrix A is the rank of A^n. The stable rank of A is zero exactly if A is nilpotent. This talk will present some results and methods related to the enumeration of certain classes of nilpotent matrices over finite fields and adapt them to the case of specified stable rank (with additional properties). A key ingredient is an algorithm due to Crabb (2006) which involves nothing more than Gaussian elimination and is considerably more elementary than other approaches to these problems in the literature.

This is joint work with Cian O'Brien and Hieu Ha Van.

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Graphical Bioinformatics: The Exact Solution to the Protein Alignment Problem

Graphical Bioinformatics originated in 1983 with a paper by Hamory and Ruskin on graphical representation of DNA (lenghty chains built from four nucleic bases). Twenty year later graphical approaches were extened to proteins (chains built from four 20 amino acids, typically having less that two hundred amino acids). The central problem in Bioinformatics is the problem of alignment of pairs of proteins or DNA in order to find the degree of their similarity. Since 1970 Computer programs, which use emprical parameters and trial-and- error approach, have been reported for solving protein aligments. Ten years ago, in 2008, I have solved graphically the protein aligment problem (no use of empirical parametrs but use of trial-and-error appraoch). Finally five years ago, in 2012, using matrices I have solved the protein alignment problem exactly (no use of emprical parameters and trial-and- error approach). In my lecture I will outline the exact solution to the protein aligment problem and illustratre its use on a pair of proteins having about 170 amino aid. Currently, the most widelly used computer program BLAST, published in 1990 (with about 5000 citations annually), found pairing for 79 amino acid while the exact solution found 85.

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Numerical Ranges over Finite Fields

Let A be an n-by-n matrix with entries in $\mathbb{F}_{q^2}$, where q is a prime power. In the finite field $\mathbb{F}_{q^2}$ we have a Frobenius map $a \mapsto a^q$ which plays the same role as complex conjugation; we use $\bar{\cdot}$ to denote this Frobenius map applied to a vector or matrix. The finite field numerical range of A, denoted $W(A)$, is defined similarly to the classical numerical range over the complex numbers: $W(A) = \left\{\overline{x}^T Ax \, : \, x \in (\mathbb{F}_{q^2})^n, \overline{x}^T x = 1\right\}$. We will describe the shapes and cardinality of $W(A)$ for 2×2 matrices, and discuss various properties of finite field numerical ranges which are analogues of classical numerical ranges.

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Results on the minimum number of distinct eigenvalues of graphs

The minimum number of distinct eigenvalues for a graph G, $q(G)$, is the minimum number of distinct eigenvalues over all real symmetric matrices whose off-diagonal entries correspond to adjacencies in G, denoted $\mathcal{S}(G)$. This relatively new parameter is of interest due to its relationship to the inverse eigenvalue problem which tries to determine all possible spectra for $\mathcal{S}(G)$. New results to be presented include bounds on $q(G)$ for Cartesian products.

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α-Adjacency Spectra of a Compound Graph of Weighted Bethe Trees

In order to study similarities and differences between the adjacency and signless-Laplacian matrices associated to a unweighted graph $\mathcal{G}$, V. Nikiforov suggests to study the convex linear combination
A_α ($\mathcal{G}$):=αD($\mathcal{G}$)+(1-α) A($\mathcal{G}$)
for $\alpha \in [0,1]$, where $A(\mathcal{G})$ and $D(\mathcal{G})$ are the adjacency matrix and the diagonal vertex degrees matrix of $\mathcal{G}$, respectively.
A weighted graph $\mathcal{G}_w$, is a graph having a weight, or a real number, associated to each edge. When in a weighted graph $\mathcal{G}_w$ we consider the weight of each edge as 1 then the weighted graph turns into an unweighted graph. Thus, the matrix $A_{\alpha,w}$ defined as
$A_{\alpha,w}$($\mathcal{G}_w$) :=αD_w($\mathcal{G}_w$) +(1-α)A_w($\mathcal{G}_w$),
where A_w($\mathcal{G}_w$) and D_w($\mathcal{G}_w$) are the weighted adjacency matrix of the weighted graph $\mathcal{G}_w$, and the weighted diagonal matrix of the row sums of A_w($\mathcal{G}_w$), respectively, extends the α-adjacency matrix to weighted graphs. We call this matrix *the weighted α-adjacency matrix of $\mathcal{G}_w$* and in this paper we characterize the *weighted α-adjacency eigenvalues* for a family of compound graphs formed by disjoint weighted generalized Bethe trees whose roots are identified to the vertices of a previously given weighted graph. Moreover, we apply our results to find the α-adjacency spectrum of the graphs with maximum α-adjacency spectral radius of the mentioned family.

This is joint work with A. Álvarez, Luis Medina, Katherine Tapia. This work was supported by Coloquios Departamento de Matemáticas. Universidad de Antofagasta. M. Robbiano was partially supported by project Proyecto VRIDT UCN16115. Katherine Tapia was support by CONICYT-PCHA/Doctorado Nacional/2016-21160357

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Fast and backward stable computation of the eigenvalues of matrix polynomials

The computation of matrix polynomials eigenvalues has gained some interest in the last decades, especially the search for adequate linearizations and good scaling techniques.

The approach which is most often used to approximate the eigenvalues of a $k \times k$ matrix polynomial of degree d is to construct a linearization, which is a $kd \times kd$ pencil, whose eigenvalues coincide with the ones of the matrix polynomial and can be approximated using the QZ method. The pencil $A - \lambda B$ typically built in this context is endowed with a particular structure: Both A and B are rank k perturbations of $kd \times kd$ unitary matrices. However, all the available structured methods for this problem are effective only when $k \ll d$.

We present a new structured method that allows to compute the eigenvalues of $k \times k$ matrix polynomials of degree d in $O(d^2k^3)$ flops, which is always asymptotically faster than the $O(d^3k^3)$ complexity obtained computing the eigenvalues of $A - \lambda B$ with an unstructured QZ.

The result is obtained by rephrasing the unitary plus rank k structure as the product of k unitary plus rank 1 matrices. This factorization can be obtained at (almost) no cost starting from the original structure, but is much more convenient from the numerical perspective. In particular, we can develop a structured method by re-using some tools developed by Aurentz et al. Several choices for this initial factorization and for the subsequent reduction to upper Hessenberg-triangular form are presented. We show that some choices are more favorable from the numerical point of view.

We prove that the presented method is backward stable on A and B, and that it reaches the same accuracy of the QZ iteration. Several numerical experiments confirm that the method is fast and accurate.

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On the minimal partial realizations of a sequence of vectors

The Berlekamp-Massey algorithm finds a linear feedback shift register of minimal length which generates a given sequence of scalars. We have reinterpreted the algorithm as a partial realization problem, and it has allowed us to parameterize the whole set of solutions. , and hold for sequences in arbitrary finite fields. In this work we explore the extension of the results to obtain a minimal partial realization of a sequence of vectors $\{Y_0, Y_1, \ldots, Y_N\}$, $Y_i \in \mathbb{K}^{q\times 1}$.

This is a joint work with Itziar Baragaña, Dpto. de Ciencias de la Computación e IA, Universidad del País Vasco-EHU, Donostia 20080, itziar.baragana@ehu.eus

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Merging of positive maps: a construction of various classes of positive maps on matrix algebras

For two positive maps $\phi_i : B(\mathcal{K}_i) \to B(\mathcal{H}_i)$, $i = 1, 2$, we construct a new linear map $\phi : B(\mathcal{H}) \to B(\mathcal{K})$, where $\mathcal{K} = \mathcal{K}_1 \oplus \mathcal{K}_2 \oplus \mathcal{C}$, $\mathcal{H} = \mathcal{H}_1 \oplus \mathcal{H}_2 \oplus \mathcal{C}$, by means of some additional ingredients such as operators and functionals. We call it a *merging* of maps ϕ_1 and ϕ_2. The properties of this construction are discussed. In particular, conditions for positivity of ϕ, as well as for 2-positivity, complete positivity, optimality and nondecomposability, are provided. In particular, we show that for a pair composed of 2-positive and 2-copositive maps, there is a nondecomposable merging of them. One of our main results asserts, that for a canonical merging of a pair composed of completely positive and completely copositive extremal maps, their canonical merging is an exposed positive map. This result provides a wide class of new examples of exposed positive maps. As an application, new examples of entangled PPT states are described.

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Phase retrieval from local measurements

We consider an instance of the phase-retrieval problem, where one wishes to recover a signal from the noisy magnitudes of its inner products with locally supported vectors. Such measurements arise, for example, in ptychography. We present theoretical and numerical results on an approach that has two important properties. First, it allows deterministic measurement constructions (which we give examples of). Second, it uses a robust, fast recovery algorithm that consists of solving a system of linear equations in a lifted space, followed by finding an eigenvector (e.g., via an inverse power iteration). This is joint work with M. Iwen, B. Preskitt, and A. Viswanathan.

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Rational and polynomial filtering, spectrum slicing, and the EVSL package

This talk will be about two different strategies for extracting extreme or interior eigenvalues of large sparse (Hermitian) matrices. The first, based on polynomial filtering, can be quite efficient in the situation where the matrix-vector product operation is inexpensive and when a large number of eigenvalues is sought, as is the case in calculations related to excited states for example. The second approach uses rational filtering and requires solving linear systems. The talk will discuss algorithmic aspects of these two approaches and will present the main features of EVSL, a library that implements filtered Lanczos and subspace iteration methods, with spectrum slicing.

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Nonlinear Sakurai-Sugiura method for electronic transport calculation

Electronic transport calculations require the computation of eigenvalues located in a ring region and their corresponding eigenvectors of a quadratic eigenvalue problem with T-palindromic structure. In this talk, we propose a technique for solving such type of quadratic problems by using the nonlinear Sakurai-Sugiura method. The proposed method reduces computational costs using a T-palindromic structure and achieves high parallel efficiency by using a contour integral. The performance of the proposed method is evaluated on Knights Landing cluster, Oakforest-PACS, in Japan.

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On the convergence rate of the DGMRES method by using the polynomial numerical hulls of matrices

The Polynomial numerical hull of order k of $A \in M_n(\mathbb{C})$ is denoted by $V^k(A)$ as follows:
$V^k(A) = \{z \in \mathbb{C} : |p(z)| \leq \|p(A)\|, \forall p \in \mathcal{P}_k\}$,
where $\mathcal{P}_k$ is the set of all polynomials of degree less than or equal k. By using this notion , we study the convergence rate of the iterative methods GMRES and DGMRES. Also, a generalization of the polynomial numerical hulls of matrices will be presented.

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Block Kronecker Ansatz Spaces for Matrix Polynomials

One approach to deal with nonlinear eigenvalue problems represented by matrix polynomials is to linearize the matrix polynomial and solve the generalized eigenvalue problem. Given some matrix polynomial $P(\lambda)$, we present a new ansatz space framework analogous to [3, Def. 3.1] which entirely contains the family of Block Kronecker matrix pencils as introduced in [1, Def. 5.1]. In contrast to [3] this concept specifically applies to nonsquare matrix polynomials. Assuming that $deg(P) = k$, we present k distinct large-dimensional *ansatz spaces* $\mathbb{G}_{\eta+1}(P), \eta = 0, 1, \ldots, k-1$, called *Block Kronecker ansatz spaces*, and prove the validity of the *Strong Linearization Theorem* [3, Thm. 4.3] in this context. Moreover, almost every matrix pencil in $\mathbb{G}_{\eta+1}(P)$ is a strong block minimal bases pencil [1, Def. 3.1] - and thus a strong linearization - for $P(\lambda)$ regardless whether $P(\lambda)$ is regular or singular. In addition to that, we show that the intersection $\bigcap_{i \in I} \mathbb{G}_{\eta_i+1}(P),\ I \subseteq \{0, 1, \ldots, k-1\}$ of any number of Block Kronecker ansatz spaces is never empty devoting special attention to the case $\mathbb{DG}_{\eta+1}(P) := \mathbb{G}_{\eta+1}(P) \cap \mathbb{G}_{k-\eta}(P)$. As one striking fact on these *double Block Kronecker ansatz spaces*, we show that they form a nested subspace sequence, that is $\mathbb{DG}_1(P) \subset \mathbb{DG}_2(P) \subset \mathbb{DG}_3(P) \subset \ldots$. Although any $\mathbb{DG}_{\eta+1}(P)$ need not contain exclusively block-symmetric pencils (as this is the case for the double ansatz space $\mathbb{DL}(P)$ [3, Def. 5.1]) we show by construction that it always contains a large subspace $\mathbb{BG}_{\eta+1}(P) \subset \mathbb{DG}_{\eta+1}(P)$ of block-symmetric pencils. For $\mathbb{BG}_{\eta+1}(P)$ we show that still almost every pencil is a strong linearization for $P(\lambda)$ even if $P(\lambda)$ is

singular. In this talk, we comprehensively characterize all three kinds of vector spaces according to [2] and show how to easily construct them. Furthermore, we analyze the connections between $\mathbb{G}_{\eta+1}(P)$ and the classical set of ansatz spaces $\mathbb{L}_1(P), \mathbb{L}_2(P)$ and $\mathbb{DL}(P)$ providing a new point of view on some classical results.

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Covering configurations derived from weighted coherent configurations

The Seidel matrix of a graph Γ may be viewed as a weight on the complete graph: edges of Γ are weighted (-1) and non-edges $(+1)$. If Γ is strongly regular with $n = 2(2k - \lambda - \mu)$, it lies in the switching class of a regular two-graph and we call the weight, analogously, *regular* on K_n. This condition on Γ is well known, as is the equivalence of regular two-graphs and antipodal double covers of complete graphs.

Generalizations of this result include the *extended Q-bipartite double* of a cometric association scheme of Martin, Muzychuk and Williford and the *regular t-graphs* of D.G. Higman. Kalmanovich established the equivalence of regular 3-graphs with cyclic antipodal 3-fold covers of K_n and showed that they give rise to certain rank 6 association schemes.

In this talk we extend this idea to the case of a coherent configuration with a regular weight taking values in the group of t^{th} roots of unity. We define the *covering configuration* induced by the weight – that is, a CC constructed from the weight via a t-fold cover. We describe an infinite family of regular 4-graphs on 2^n vertices whose covering configurations are non-symmetric schemes of order 2^{n+2}.

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On classes of non-normal matrices/operators

In this talk, we show some results of matrices/operators acting on indefinite metric spaces and those of geometric means for two operators with positive definite real part.

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Faster Constrained Optimization via Approximate Projections

From an algorithmic perspective, many high-dimensional estimation problems such as compressed sensing and matrix completion reduce to a constrained optimization problem. While the constraints (such as sparsity, group sparsity, low rank, etc.) are essential to achieve a good sample complexity, they also pose an algorithmic challenge. In this talk, I will show how approximate projections can be incorporated into projected gradient descent in order to address this challenge. The resulting framework enables faster recovery algorithms for a wide range of structures including group sparsity, graph sparsity, and low-rank matrices.

Based on joint work with Michael Cohen, Chinmay Hegde, Piotr Indyk, and Stefanie Jegelka.

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Multiplicities of Demazure Flags

Joint work with Vyjayanthi Chari (University of California, Riverside)

Demazure modules in highest weight representations of affine Lie algebras have been the focus of great study. In this talk, I will define Demazure flags of Demazure modules for the current algebra in the case of $A_1^{(1)}$ and the associated multiplicities of such Demazure flags. I will then discuss results known in small levels and relate these results to combinatorial objects. Lastly, I will discuss future directions for determining multiplicities for all levels.

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Quantum Systems Theory as Reflected by Numerical Ranges

Which quantum states can be reached from a given initial state under the evolution of a controlled quantum dynamical system? What is the corresponding set of all expectation values to a given observable?

We will illustrate how the answers to these quantum engineering questions [1,2] relate to numerical ranges, C-numerical ranges and more recent derived notions determined by orbits of proper subgroups of the unitaries [3].

Quantum systems theory in terms of Lie groups [1] and Lie semigroups [4] with their symmetries provides a unified framework to pinpoint the dynamic behaviour of closed and open quantum systems under all kinds of controls.

Within this picture, expectation values not only connect naturally to numerical ranges [3,5], they also put challenges for the future.

The lecture contains joint work mainly with Gunther Dirr, Robert Zeier, Ville Bergholm. It was supported in part by the EU programmes Q-ESSENCE and SIQS, by DFG through SFB˙631 and FOR˙1482, and by the Excellence Network of Bavaria through QCCC and ExQM.

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On the Riemann-Hilbert approach to Einstein's field equations

Einstein's field equations (non-linear PDE's in four dimensions) can be studied by means of a Riemann-Hilbert approach when restricting to the subset of solutions that only depend on two of the four spacetime coordinates. The resulting field equations in two dimensions can be recast in terms of an auxiliary linear system, the so-called Breitenlohner-Maison linear system. The latter can be solved by studying an associated Riemann-Hilbert matrix factorization problem for a so-called monodromy matrix. In this work we study how to obtain new solutions to the field equations in two dimensions through group multiplication acting on a seed monodromy matrix.

This is joint work with Gabriel Lopes Cardoso. This work was supported by the Calouste Gulbenkian Foundation, Programa Novos Talentos em Matemática 2016/17

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A relaxed gradient based algorithm for solving generalized coupled Sylvester matrix equations

The present work proposes a relaxed gradient based iterative (RGI) algorithm to find the solutions of coupled Sylvester matrix equations $AX + YB = C, DX + YE = F$. It is proved that the proposed iterative method can obtained the solutions of the coupled Sylvester matrix equations for any initial matrices. Then the RGI algorithm is extended to the generalized coupled Sylvester matrix equations of the form $A_{i1}X_1B_{i1} + A_{i2}X_2B_{i2} + \ldots + A_{ip}X_pB_{ip} = C_i, (i = 1, 2, \ldots, p)$. Finally, two numerical examples are included to demonstrate that the introduced iterative algorithm is more efficient than the least-squares iterative (LSI) algorithm [Ding, 2005] and the gradient based iterative (GI) algorithm [Ding, 2006].

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C-algebras arising from integral Fourier matrices

A Fourier matrix S is a unitary symmetric matrix that produces integral structure constants using Verlinde's formula $N_{ijk} = \sum_l S_{li} S_{lj} S_{lk} S_{l0}^{-1}$. We have studied C-algebras that arise from Fourier matrices. We have solved some open problems due to Cuntz about integral Fourier matrices. In this talk we will solve one such open problem by showing that every entry of a zero-free column in an integral Fourier matrix must be ± 1.

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Using Nonnegative Matrix Factorization to Analyze a Set of Documents

Students are often unaware of the fact that linear algebra is commonly used in the analysis of real-world data. We exhibit an assignment that gives students hands-on experience with automatically collecting and analyzing text to reveal latent structure. In particular, we provide tools to automatically generate a term-by-document matrix from either a corpus of student-supplied documents or student-supplied Wikipedia search terms, and tools to apply non-negative matrix factorization (NMF) to this matrix. Students see how hidden structure is revealed by this decomposition, and in the process deepen their understanding of the notions of matrix multiplication, low rank matrices, and sparse matrices, while giving a hint at the powers that further study of linear algebra might grant them.

Joint work with Barak Pearlmutter (NUI Maynooth) and Miao Wei (NUI Maynooth).

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From positive matrices to negative polynomial coefficients

The nonnegative inverse eigenvalue problem, the problem of characterising all lists of eigenvalues of entry-wise nonnegative matrices, motivated the construction of matrices with nonnegative entries and a given set of eigenvalues. Constructions based on companion matrices proved to be one of the most fruitful approaches to this problem. We will review several different companion-type constructions, and learn about some extensions of classical results on the roots of polynomials developed in the process. The talk concludes with some related results on the coefficients of power series.

Joint work with Richard Ellard (University College Dublin), Thomas Laffey (University College Dublin) and Raphael Loewy (Technion).

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Virtual species and matrix solution of Eigen's equations

Eigen's phenomenological rate equations under constant total organization form a coupled system of ordinary quadratic differential equations. They provide a useful tool for considering growth and selection of competing species, capable of interpretation at various levels from the submolecular to the ecological. In this talk, we will discuss a matrix operator approach to Eigen's equations. The approach is based on the concept of a virtual species, representing an autonomously viable mix of actual species.

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On solutions to the matrix equations $XB - AX = CY$ and $XB - A\widehat{X} = CY$

The solution of the generalized Sylvester real matrix equation $XB - AX = CY$ is important in stability analysis and controller design in linear systems. This paper presents a explicit solution to the generalized Sylvester real matrix equation $XB - AX = CY$. Based on the derived explicit solution to the considered generalized Sylvester real matrix equation, a new approach is provided for obtaining the solutions to the generalized Sylvester quaternion j-conjugate matrix equation $XB - A\widehat{X} = CY$ using of the real representation of a quaternion matrix. The closed form solution is established in an explicit form for this generalized Sylvester quaternion j-conjugate matrix equation. The existing complex representation method requires the coefficient matrix A to be a block diagonal matrix over complex field, while it is any suitable dimension quaternion matrix in the present paper. Therefore, we generalize the existing results.

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Partial geometric designs obtained from association schemes

Bose, Shrikhande and Singhi introduced the notion of partial geometric design in their article, *Edge regular multigraphs and partial geometric designs with an application to the embedding of quasi designs* (1976). Neumaier investigated the parametric properties of partial geometric designs and their relationship to other block designs in his article, $t\frac{1}{2}$*-designs*, *JCT* A **28** (1978), 226-248. Brouwer, Olmez and Song showed that partial geometric designs give rise to directed strongly regular graphs in *Directed strongly regular graphs from* $1\frac{1}{2}$*-designs*, *Eur J Combin* **33**(6) (2012), 1174-1177. Since then, many researchers have discovered various sources of partial geometric designs and interesting connections of their designs to other combinatorial structures. Recently, we (with Nowak and Olmez) found a family of partial geometric designs from three-class fusion schemes of Hamming schemes. In this talk, we take another step and discuss further connections of these designs with certain symmetric association schemes.

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Structured nonnegative inverse elementary divisors problem

The nonnegative inverse elementary divisors problem (NIEDP) is the problem of determining necessary and sufficient conditions for the existence of an $n \times n$ entrywise nonnegative matrix A with prescribed elemenrtary divisors. If the nonnegative matrix A is required to have a particular structure we have the structured NIEDP, which is the problem we consider in this work. The NIEDP is strongly related to the nonnegative inverse eigenvalue problem (NIEP), which is the problem of finding necessary and sufficient conditions for the existence of an $n \times n$ entrywise nonnegative matrix with prescribed spectrum $\Lambda = \{\lambda_1, \ldots, \lambda_n\}$. If Λ is the spectrum of a nonnegative matrix A we say that Λ is realizable and that A is the realizing matrix. The NIEDP contains the NIEP and both problems are equivalent if the prescribed eigenvalues are distinct. Both problems remain unsolved. We approach the NIEDP module the NIEP, to take advantage of what is known about the NIEP. We give sufficient conditions for the existence of a solution to the NIEP and the NIEDP for certain structured nonnegative matrices. In particular, we show that companion matrices are similar to persymmetric and Toeplitz matrices. As a consequence, we show that all realizable list $\{\lambda_1, \ldots, \lambda_n\}$ in the left half plane ($Re\lambda_i \leq 0$, $i = 2, \ldots, n$) is also realizable by a persymmetric and by a Toeplitz nonnegative matrix. This work was supported by Fondecyt grant 1170313

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Embodied, symbolic and formal worlds: A basis for the vector space of mathematical thinking

Linear algebra is made out of many languages and representations. Instructors and text books often translate these languages and modes of thinking fluently, not allowing students a chance to digest them as they assume that students will pick up their understandings along the way. In reality most students do not have the cognitive framework to perform the move that is available to the mathematicians. In this talk, employing Tall's three-world model, we present specific linear algebra tasks that are designed to encourage students to move between the embodied, symbolic and formal worlds of mathematical thinking. Our working hypothesize is that by creating opportunities to navigate between the worlds we may encourage students to think in multiple modes of thinking which result in richer conceptual understanding. Some preliminary results illustrating these ideas will be presented.

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Minimal upper bounds in the Loewner order: characterizations and parametrization.

We study the set of minimal upper bounds of finitely many symmetric matrices, in the Loewner order. In the case of two matrices, we provide a parametrization of this set in terms of the quotient of the indefinite orthogonal group $O(p, q)$ by the maximal compact subgroup $O(p) \times O(q)$. Moreover, we show that a matrix is a minimal upper bound of $A_1, \ldots A_p$ if and only if it is positively exposed, meaning that it is the unique upper bound that minimizes a function of the form $X \mapsto \text{trace}(CX)$ where C is a positive definite matrix. Finally, when only two matrices are involved, we show that most usual selections of minimal upper bounds can be computed analytically.

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Motivating Examples, Meaning and Context in Teaching Linear Algebra

In a linear algebra course we often present and develop a new concept without paying much attention to motivation, real-life meaning or context. It is fairly standard for a section in a textbook to consist of a few definitions, a couple of theorems and their proofs, and a few somewhat contrived examples or applications in which the given ideas are illustrated. Textbooks typically do a good job with the 'what' and the 'how' but not as well with the 'why' Often it isn't until subsequent sections that students begin to understand the importance and use of the ideas learned in the previous sections. While this is sometimes the inherent nature of mathematics, it doesn't usually have to be this way. Instead, we (textbook authors and course instructors) have a golden opportunity to simultaneously motivate the need for the ideas and motivate the students to want to learn about those ideas. If students care, they will learn.

I will discuss how we can better address the 'why' through relevant and thought-provoking examples to better motivate the need for the ideas taught in the course and to simultaneously pique the interest of the student. I will look at a few (of the many) examples that could be used to motivate the need for the ideas, rather than simply giving the examples and applications as somewhat of an afterthought. I will also talk about how we can give better context and meaning to ideas to enrich student learning.

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The nonexistence of a distance-regular graph with intersection array $\{22, 16, 5; 1, 2, 20\}$

We prove that a distance-regular graph with intersection array $\{22, 16, 5; 1, 2, 20\}$ does not exist. To prove this, we assume that such a graph exists and derive some combinatorial properties of its local graph. Then we construct a partial linear space from the local graph to display the contradiction.

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When are nonconvex optimization problems not scary?

Nonconvex optimization plays an important role in problem solving across science and engineering. In theory, even guaranteeing a local minimizer is NP-hard. In practice, more often than not, simple iterative methods work surprisingly well in specific applications.

In this talk, I will describe a family of nonconvex problems that can be solved to global optimality using simple iterative methods, which are initialization-free'. This family has the characteristic structure that (1) all local minimizers are global, and (2) all saddle points have non-degenerate Hessians. Examples lying in this family arise from applications such as learning sparsifying basis for signals (aka sparse dictionary learning), and recovery of images from phaseless measurements (aka generalized phase retrieval). In both examples, the benign global structure allows us to derive novel performance guarantees.

Completing and enriching this framework is an active research endeavor undertaken by several research communities. The ultimate goal is to enable practitioners to deploy the theory and computational tools with minimal amount of efforts, paralleling convex analysis and optimization. I will highlight open problems to be tackled to move forward.

Joint work with Qing Qu (Columbia) and John Wright (Columbia). More details can be found in my PhD thesis under the same title.

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Solutions of multilinear systems and characterizations for spectral radius of tensors

There are two parts in this talk. (1) We obtain some solutions of the multilinear systems by using the generalized inverses of tensors, which extend the conclusions on the solutions of matrices equations. (2) We give some characterizations for the spectral radius of nonnegative weakly irreducible tensors via digraphs, which extend the work of [R.A. Brualdi, Matrices, eigenvalues, and directed graphs, Linear and Multilinear Algebra 11 (1982) 143-165.]

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The spectral radius of a graph with no induced $K_{s,t}$

Let H be a graph and $t \geq s \geq 2$ be integers. We prove that if G is an n-vertex graph with no copy of H and no induced copy of $K_{s,t}$, then $\lambda(G) = O\left(n^{1-1/s}\right)$ where $\lambda(G)$ is the spectral radius of the adjacency matrix of G. Our results are motivated by results of Babai, Guiduli, and Nikiforov bounding the maximum spectral radius of a graph with no copy (not necessarily induced) of $K_{s,t}$. This is joint work with Vlado Nikiforov and Craig Timmons.

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Geometry and unitarily similarity orbit of a matrix

Given an $n \times n$ matrix A, the celebrated Toeplitz-Hausdorff theorem asserts that the classical numerical range $\{x^*Ax : x \in \mathbb{C}^n : x^*x = 1\}$ is a convex set, where $\mathbb{C}^n$ is the vector space of complex n-tuples and x^* is the complex conjugate transpose of $x \in \mathbb{C}^n$. Among many interesting generalizations, we will focus our discussion on those in the context of Lie structure, more precisely, compact connected Lie groups and semisimple Lie algebras. Some results on convexity and star-shapedness will be presented.

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Some aspects of 2-positive linear maps on matrix algebras

Following an idea of M.-D. Choi, we obtain a decomposition theorem for k-positive linear maps from M_m to M_n, where $2 \leq k < \min\{m, n\}$. As a consequence, we give an affirmative answer to Kye's conjecture (also solved independently by Choi) that every 2-positive linear map from M_3 to M_3 is decomposable. Some related implications in quantum information theory will be discussed. This talk is based on joint work with Y. Yang and D. H. Leung.

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Polynomial system solving and numerical linear algebra

This talk is about the problem of solving systems of polynomial equations using numerical linear algebra techniques. Let k be an algebraically closed field and let $p_1 = p_2 = \ldots = p_n = 0$ define such a system in k^n: $p_i \in k[x_1, \ldots, x_n]$. Let I be the ideal generated by these polynomials. We are interested in the case where the system has finitely many isolated solutions in k^n. It is a well known fact that this happens if and only if the quotient ring $k[x_1, \ldots, x_n]/I$ is finite dimensional as a k-vector space. Multiplication in $k[x_1, \ldots, x_n]/I$ by a polynomial f is a linear operation. Choosing a k-basis B for $k[x_1, \ldots, x_n]/I$, this multiplication can be represented by a matrix m_f called a *multiplication matrix*. These multiplication endomorphisms of the quotient algebra provide a natural linear algebra formulation of the root finding problem. Namely, the eigenstructure of the multiplication matrices reveals the solutions of the system. Our aim is to compute the multiplication matrices in a numerically stable way by exploiting the freedom of choice of the k-basis for the quotient ring. Methods using Groebner bases to calculate the multiplication matrices make this choice implicitly. From a numerical point of view, this is often not a very good choice. Significant improvement can be made by using elementary numerical linear algebra techniques on a Macaulay-type matrix, which is built up by the coefficients of the p_i. In this talk we will present this technique and show how the resulting method can handle challenging systems, both dense and sparse with a large number of (possibly multiple) solutions.

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Leonard triples of q-Racah type and their pseudo intertwiners

Let $\mathbb{F}$ denote a field, and let V denote a vector space over $\mathbb{F}$ with finite positive dimension. Pick a nonzero $q \in \mathbb{F}$ such that $q^4 \neq 1$, and let A, B, C denote a Leonard triple on V that has q-Racah type. We show that there exist invertible W, W', W'' in $\mathrm{End}(V)$ such that

(i) A commutes with W and $W^{-1}BW - C$;
(ii) B commutes with W' and $(W')^{-1}CW' - A$;
(iii) C commutes with W'' and $(W'')^{-1}AW'' - B$.

Moreover each of W, W', W'' is unique up to multiplication by a nonzero scalar in $\mathbb{F}$. We show that the three elements $W'W, W''W', WW''$ mutually commute, and their product is a scalar multiple of the identity.

A number of related results are obtained. We call W, W', W'' the pseudo intertwiners for A, B, C. We will discuss how pseudo intertwiners are related to Q-polynomial distance-regular graphs.

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Disease spread on networks: integrating structure and dynamics through a generalized inverse

A fundamental issue for understanding disease dynamics on networks is how network structure and node characteristics combine to influence disease spread. I will discuss a generalized inverse, called the absorption inverse, that arises naturally in this context. The absorption inverse is connected to transient random walks on the graph, and can be used to derive a distance metric, centrality measures, and community detection algorithms that integrate both structure and dynamics. I will introduce the absorption inverse and describe some of these measures, together with implications for disease dynamics. This is joint work with Karly Jacobsen.

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On the isomorphism problem of certain algebraic quantizations

In this talk we will discuss the problem of recovering the original Poisson structure from its quantization. We will be particularly interested in the cases of algebras of differential operators and enveloping algebras of Lie algebras.

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Fast Determination of the Tensorial and Simplicial Bernstein Enclosure

The underlying problems of our talk are unconstrained and constrained global polynomial optimization problems over boxes and simplices. One approach for their solution is based on the expansion of a (multivariate) polynomial into Bernstein polynomials of the objective function and the constraints polynomials. This approach has the advantage that it does not require function evaluations which might be costly if the degree of the polynomials involved is high.

The coefficients of this expansion are called the *Bernstein coefficients*. These coefficients can be rearranged in a multi-dimensional array, the so-called *Bernstein patch*. From these coefficients we get bounds for the range of the objective function and the constraints over a box or a simplex, see [1, 2]. We can improve the enclosure for the range of the polynomial under consideration by elevating the degree of its Bernstein expansion or by subdivision of the region. Subdivision is more efficient than degree elevation. The complexity of the traditional approach for the computation of these coefficients is exponential in the number of the variables.

In [1] Garloff proposed a method for computing the Bernstein coefficients of a bivariate polynomial over the unit box and the unit triangle by using a forward difference operator. We propose some efficient matrical methods that involve only matrix operations such as multiplication, transposition, and reshaping as Ray and Nataraj's method, see [4]. Our methods are superior over Garloff's and Ray and Nataraj's method for the computation of the Bernstein coefficients over the unit and a general box and the standard simplex. We also propose a matricial method for the computation of the Bernstein coefficients over subboxes and subsimplices when the original box and simplex are subdivided, respectively.

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This is joint work with J. Garloff (University of Applied Sciences/HTWG Konstanz, institute for Applied Research and University of Konstanz, Department of Mathematics and Statistics, Konstanz, Germany)

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Ordering starlike trees by their indices

The index of a graph is the largest eigenvalue of its adjacency matrix. A starlike is a tree in which a single vertex has degree larger than 2.

Given a natural number n, we show how to order all the non isomorphic starlike trees by their indices. In particular, no two starlike trees have equal index.

This may be a surprising result because the number of starlikes is large for a fixed n. Additionally, the indices are numerically very close, making it difficult to compare. To order the indices, we use a technique based on a diagonalization procedure that is originally designed to locate eigenvalues of trees. We believe this technique may be applied to a variety of problems is spectral graph theory.

Work reported here is co-authored by Elismar R. Oliveira and Dragan Stevanovic.

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Students' learning through a modeling course on elementary Linear Algebra

Difficulties in the learning Linear Algebra have been reported in the Mathematics Education literature. Researchers consider their cause as being related to its being too abstract for students. In order to help students in their learning of Linear Algebra a strategy was designed where several fundamental Linear Algebra concepts were introduced by means of modeling situations that were complemented with activities based on a learning theory (APOS Theory). Results of a consistent use of this strategy show that students' schemas develop through the course. Results also put forward some elements that seem to be key in the development of their schema and learning.

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Global convergence of Jacobi-type algorithms for symmetric tensor diagonalization

Symmetric tensors (or sets of symmetric matrices), in general, cannot be diagonalized (jointly diagonalized) by orthogonal transformations. Motivated by applications in signal processing, we consider a family of Jacobi-type algorithms for approximate orthogonal diagonalization. For the Jacobi-type algorithm of [SIAM J. Matrix Anal. Appl., 2(34):651–672, 2013], we prove its global convergence in the case of simultaneous orthogonal diagonalization of symmetric matrices or 3rd-order tensors. We also propose a new proximal Jacobi-type algorithm and prove its global convergence for a wide range of tensor problems.

This is joint work with Jianze Li (Tianjin University) and Pierre Comon (GIPSA-lab, CNRS and Univ. Grenoble Alpes).

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Solving polynomial eigenvalue problems by a scaled block companion linearization

The *polynomial eigenvalue problem* (PEP) is to look for nonzero vectors v (right eigenvectors) and corresponding eigenvalues λ such that

$$P(\lambda)v = 0,$$

where $P(z)$ is an $s \times s$ matrix polynomial. The standard way to solve the PEP is via *linearization*, the latter being a square matrix polynomial $L(z)$ of degree one such that

$$E(z)L(z)F(z) = \begin{bmatrix} P(z) & 0 \\ 0 & I \end{bmatrix}$$

with $E(z)$ and $F(z)$ unimodular matrix polynomials. An abundance of linearizations have appeared in the literature based on the representation of $P(z)$ in different bases, e.g., degree graded bases such as the monomial basis, the Chebyshev basis, ..., or interpolation bases, such as the Lagrange polynomials.

If the matrix polynomial $P(z)$ has degree d and is given in the monomial basis, i.e., as

$$P(z) = \sum_{i=0}^{d} P_i z^i,$$

then

$$L(z) = \begin{bmatrix} P_d & P_{d-1} & \cdots & P_1 & P_0 \\ I_s & -zI_s & & & \\ \vdots & & \ddots & & \\ 0_s & & & I_s & -zI_s \end{bmatrix}$$

is a block companion linearization of the grade $d+1$ matrix polynomial $0z^{d+1}+P(z)$. In this talk, we describe a two-sided diagonal scaling of $L(z)$ based on the max-times roots of the associated max-time polynomial

$$tp(x) = \max_{0\leq i\leq d} ||P_i||x^i.$$

We show that this scaling when combined with a deflation of the s extra eigenvalues at infinity allows an adapted version of the QZ algorithm to compute the eigenvalues of P with small backward errors. Unlike Gaubert and Sharify's approach, which uses the max-times roots of $tp(x)$ to scale the eigenvalue parameter and require one call of the QZ algorithm per max-times root, our approach only requires one call to the QZ algorithm.

This is joint work with Francoise Tisseur.

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A rational filtering connection between contour integration and rational Krylov methods for large scale eigenvalue problems

Contour integration methods and rational Krylov methods are two important classes of numerical methods for computing eigenvalues in a given interval or region of the complex plane. Using rational filtering based on a quadrature rule, we present connections between two variants of these methods. We prove for linear eigenvalue problems that with a particular choice of the starting basis matrix and the rational filter, these methods construct the same subspace and hence compute the same Ritz pairs. Consequently, this equivalence allows us to combine good properties of both worlds. Firstly, the connections of rational Krylov methods with contour integration methods provide better stopping criteria for the former based on the rank test in the latter. Secondly, this connection allows for an efficient implementation of contour integration via rational Krylov which can significantly reduce the computational cost. We also introduce the contour filtered compact rational Krylov method for nonlinear eigenvalue problems, since for these problems the connection of contour integration methods with rational filtering is lost. Finally, we illustrate the connections for both linear and nonlinear eigenvalue problems.

This is joint work with K. Meerbergen and W. Michiels.

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Inequalities on Spectral Bounds for Matrices in a Stage-Structured Population Model

The spectral bound of a convex combination of two matrices of special form is compared with the convex combination of their individual spectral bounds. The matrices are essentially non-negative, and arise from considering the influence of environmental variation on a linear stage-structured population model. By using $\mathcal{M}$-matrix theory, the problem is converted to one involving the spectral radius of a related matrix. Theoretical results are derived for special cases of an arbitrary number of stage classes, and in particular confirm all previous numerical observations for the model with two stage classes.

This is joint work with Alan Hastings, U.C. Davis, and is supported by an NSERC Discovery Grant.

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Robustness and Perturbations of Minimal Bases

Polynomial minimal bases of rational vector subspaces are a classical concept that plays an important role in control theory, linear systems theory, and coding theory. It is a common practice to arrange the vectors of any minimal basis as the rows of a polynomial matrix and to call such matrix simply a minimal basis.

Very recently, minimal bases, as well as the closely related pairs of dual minimal bases, have been applied to a number of problems that include the solution of general inverse eigenstructure problems for polynomial matrices, the development of new classes of linearizations and ell-ifications of polynomial matrices, and backward error analyses of complete polynomial eigenstructure problems solved via a wide class of strong linearizations. These new applications have revealed that although the algebraic properties of minimal bases are rather well understood, their robustness and the behavior of the corresponding dual minimal bases under perturbations have not yet been explored in the literature, as far as we know. Therefore, the main purpose of this paper is to study in detail when a minimal basis M(s) is robust under perturbations, i.e., when all the polynomial matrices in a neighborhood of M(s) are minimal bases, and, in this case, how perturbations of M(s) change its dual minimal bases. In order to study such problems, a new characterization of whether or not a polynomial matrix is a minimal basis in terms of a finite number of rank conditions is introduced and, based on it, we prove that polynomial matrices are generically minimal bases with very specific properties. In addition, some applications of these results are discussed.

This is joint work with Froilan Dopico from the Universidad Carlos III de Madrid. It is supported by the Belgian network DYSCO funded by the Interuniversity Attraction Poles Programme initiated by the Belgian Science Policy Office through grant IAP VII/19 and by the Ministerio de Economia, Industria y Competitividad of Spain and by Fondo Europeo de Desarrollo Regional of EU through grants MTM-2015-68805-REDT and MTM-2015-65798-P.

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Fast and Stable Roots of Polynomials via Companion Matrices

In this talk we present a fast and stable algorithm for computing roots of polynomials. The roots are found by computing the eigenvalues of the associated companion matrix. A companion matrix is an upper Hessenberg matrix that is of unitary–plus–rank–one form, that is, it is the sum of a unitary matrix and a rank–one matrix. When running Francis's implicitly–shifted QR algorithm this property is preserved, and exactly that is exploited here.

To compactly store the matrix we will show that only $3n-1$ rotators are required, so the storage space is O(n). In fact, these rotators only represent the unitary part, but we will show that we can retrieve the rank-one part from the unitary part with a trick. It is thus not necessary to store the rank-one part explicitly. Francis's algorithm tuned for working on this representation requires only O(n) flops per iteration and thus $O(n^2)$ flops in total. The algorithm is normwise backward stable and is shown to be about as accurate as the (slow) Francis QR algorithm applied to the companion matrix without exploiting the structure. It is also faster than other $O(n^2)$ methods that have been proposed, and its accuracy is comparable or better.

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Recursive constructions for spectrally arbitrary patterns

A sign pattern matrix has entries from $\{+, -, 0\}$. A pattern is spectrally arbitrary if the combinatorial pattern imposes no restrictions on the possible eigenvalues of a real matrix with the pattern. Recently, a digraph method, called triangle extension, was developed to build higher order spectrally arbitrary patterns out of lower order patterns. We extend this method by reframing it as a matrix bordering technique. We describe recursive constructions of spectrally arbitrary patterns using our bordering technique. A slight variation of this technique can also be used to construct inertially arbitrary sign patterns. Joint work with D. Olesky and P. van den Driessche.

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Subspace acceleration for computing the Crawford number

The Crawford number is defined as the minimal distance to zero of the numerical range of a given matrix. It can, for example, be used to measure the distance to the nearest non-definite matrix pair. We present a subspace framework to accelerate existing methods for computing the Crawford number. This is in particular useful for large scale problems. Our approach is formally the same as existing subspace methods for Hermitian eigenvalue optimization. However, we prove that the order of local convergence is at least $1 + \sqrt{2} \approx 2.4$. Numerical experiments indicate this bound is sharp.

This is joint work with Daniel Kressner (EPF Lausanne) and Ding Lu (University of Geneva).

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Short curves in orbits of unitary subgroups

We will consider unitary orbits of self-adjoint operators in a Hilbert space. The rectifiable distance we will use is the one obtained from the Finsler metric defined by the quotient norm of the Lie algebras involved. The explicit parametrization of the geodesic curves in these homogeneous spaces often involves the resolution of open problems in operator algebras that will be commented. We will describe properties of certain subgroups and subsets of the unitary group related to this problem and analyze applications and particular examples.

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New Results for Provably Correct Dynamic Robust Principal Components Analysis (PCA)

Robust PCA (RPCA) refers to the problem of PCA in the presence of sparse outliers. In other words, it is the problem of separating a given data matrix into the sum of a sparse matrix and a low-rank matrix. The column space of the low-rank matrix then gives us the desired principal subspace. The dynamic RPCA problem, introduced in the work of Qiu and Vaswani (Allerton 2010), assumes that the true (uncorrupted) data vectors lie in a low-dimensional subspace that can change with time, albeit fislowlyfi. The goal is to track this changing subspace over time in the presence of sparse outliers. The initial subspace is assumed to be known accurately. This can be obtained in one of two ways. A standard static RPCA technique, such as PCP (Candes et al. or Hsu et al.) or AltProj (Netrapalli et al.), can be applied to a short initial data sequence to get this. Alternatively, if a short initial sequence of outlier-free data is available, simple EVD on it gives the initial subspace.

The only existing complete correctness guarantees for dynamic RPCA are the ones given in our earlier work. However, these have many important limitations which the current work removes. First, the slow subspace assumption of the earlier work is an unrealistic one since it requires a tight bound on the eigenvalue along the newly added direction for a period of time after the subspace change. We remove this assumption; and also make the slow subspace change model more smooth and hence more realistic. In fact, the latter ensures the former. Second, the earlier works needed a strong assumption on the type of outlier support change. We weaken that and instead only need an assumption similar to the one needed by AltProj or PCP (Hsu et al.'s result). Third, the required delay between subspace change times in earlier works depended on $1/\epsilon^2$ where ϵ was the final desired error. Our current result removes this unnecessary dependence. The delay now only depends on $(-\log \epsilon)$ which makes it much smaller.

(This talk is based on joint work with my student Praneeth Narayanamurthy)

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Clustering subgaussian mixtures by semidefinite programming

We introduce a model-free relax-and-round algorithm for k-means clustering based on a semidefinite relaxation due to Peng and Wei. The algorithm interprets the SDP output as a denoised version of the original data and then rounds this output to a hard clustering. We provide a generic method for proving performance guarantees for this algorithm, and we analyze the algorithm in the context of subgaussian mixture models. We also study the fundamental limits of estimating Gaussian centers by k-means clustering in order to compare our approximation guarantee to the theoretically optimal k-means clustering solution.

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Hyperbolicity and reciprocal linear spaces

A reciprocal linear space is the image of a linear space under coordinate-wise inversion. This nice algebraic variety appears in many contexts and its structure is governed by the combinatorics of an underlying hyperplane arrangement. A reciprocal linear space is also an example of a hyperbolic variety, meaning that there is a family of linear spaces all of whose intersections with it are real. This special real structure is witnessed by a determinantal representation of its Chow form in the Grassmannian. For generic linear spaces, these determinantal formulas are closely related to the Laplacian of the complete graph and generalizations to simplicial matroids. In this talk, I will introduce reciprocal linear spaces and discuss the relation of their algebraic properties to their combinatorial and real structure.

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Quantum f-divergence preserving maps on positive semidefinite operators acting on finite dimensional Hilbert spaces

We determine the structure of all bijections on the cone of positive semidefinite operators which preserve the quantum f-divergence for an arbitrary strictly convex function f defined on the positive halfline. It turns out that any such transformation is implemented by either a unitary or an antiunitary operator. The talk is based on the paper [D. Virosztek, Linear Algebra Appl. 501 (2016), 242-253].

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Transition asymptotics of Toeplitz determinants and their applications

The study of the asymptotics of Toeplitz determinants is important because of a vast number of applications in random matrix theory and mathematical physics. These asymptotics are well understood for many symbol classes, such as smooth Szegö symbols, and symbols with Fisher-Hartwig (F-H) singularities of jump and/or root type. By introducing an additional parameter in the symbol, we can consider what is called transition asymptotics. In the paper fiEmergence of a singularity for Toeplitz determinants and Painleve V,fi Clayes, Its and Krasovsky considered the transition case between a Szego and a F-H symbol with one singularity. In this talk we discuss a transition in which we see emergence of additional singularities. In that case however, we need to consider so-called F-H representations and the Tracy-Basor conjecture. These types of results model phase transitions in numerous problems arising in statistical mechanics, one of which will be mentioned in the talk. Joint work with Kasia Kozlowska.

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A Superfast Multi-Rank Eigenvalue Update: Algorithm, Analysis, and Applications

We present some recent developments to the algorithms, analysis, and applications of divide-and-conquer eigenvalue algorithms for hierarchically structured matrices. Our contributions include a novel new approach for the rank-k update to the symmetric eigenvalue problem which is stable, has $O(k^2n)$ complexity, and great data locality. This leads to an elegant approach for dealing with the pathological case of clustered eigenvalues. We test our new algorithms on applications including semidefinite programming optimization problems.

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A System of Matrix Equations over the Quaternion Algebra with Applications

We in this talk give necessary and sufficient conditions for the existence of the general solution to the system of matrix equations $A_1X_1 = C_1$,$AX_1B_1 + X_2B_2 = C_3$, $A_2X_2 + A_3X_3B = C_2$ and $X_3B_3 = C_4$ over the quaternion algebra $\mathbb{H}$, and present an expression of the general solution to this system when it is solvable. Using the results, we give some necessary and sufficient conditions for the system of matrix equations $AX = C$, $XB = C$ over $\mathbb{H}$ to have a reducible solution as well as the representation of such solution to the system when the consistency conditions are met. A numerical example is also given to illustrate our results. As another application, we give the necessary and sufficient conditions for two associated electronic networks to have the same branch current and branch voltage and give the expressions of the same branch current and branch voltage when the conditions are satisfied.

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Learning dynamical systems from highly corrupted measurements

We consider the problem of learning the governing equations in a system of ODES from possibly noisy snapshots of the system in time. Using a combination of tools from ergodic theory and compressive sensing, we show that if the governing equations are polynomial of given maximal degree, then the polynomial coefficients can be recovered exactly — even when most of the snapshots are highly corrupted by noise — under certain ergodicity assumptions. Important in high-dimensional problems, such coefficients can be exactly recovered even when the number of measurements is smaller than the dimension of the polynomial space, assuming the underlying polynomial expansions are sparse. Finally, we present several numerical results suggesting that L1-minimization based recovery algorithms can exactly recover dynamical systems in a much wider regime.

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Inquiry-Oriented Linear Algebra: An overview and an example

The Inquiry-Oriented Linear Algebra (IOLA) curricular materials are designed to be used for a first course in linear algebra at the university level. Many of the tasks in the IOLA materials are created to facilitate students engaging in task settings in such a way that their mathematical activity can serve as a foundation from which more formal mathematics can be developed. The materials include rationales for design of the tasks, suggestions for promoting student and instructor inquiry, and examples of typical student work. In the presentation, I will illustrate the IOLA materials through explaining a task sequence that supports students' reinvention of change of basis and eigentheory.

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Boundary Representations of Reproducing Kernels in the Hardy Space

For a singular probability measure μ on the circle, we show the existence of positive matrices on the unit disc which admit a boundary representation on the unit circle with respect to μ. These positive matrices are constructed in several different ways using the Kaczmarz algorithm. Some of these positive matrices correspond to the projection of the SzegS kernel on the disc to certain subspaces of the Hardy space corresponding to the normalized Cauchy transform of μ. Other positive matrices are obtained which correspond to subspaces of the Hardy space after a renormalization, and so are not projections of the SzegS kernel. We show that these positive matrices are a generalization of a spectrum or Fourier frame for μ, and the existence of such a positive matrix does not require μ to be spectral.

For an arbitrary measure μ, the positive matrices on the unit disc which admit a boundary representation on the unit circle with respect to μ is characterized by a matrix equation using an 'Abel product', which we introduce.

This is joint work with John Herr and Palle Jorgensen.

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Title: Guarantees of Riemannian Optimization for Low Rank Matrix Reconstruction

We establish theoretical recovery guarantees of a family of Riemannian optimization algorithms for low rank matrix reconstruction, which is about recovering an $m \times n$ rank r matrix from $p < mn$ number of linear measurements. The algorithms are first interpreted as the iterative hard thresholding algorithms with subspace projections. Based on this connection, we show that with a proper initial guess the Riemannian gradient descent method and a restarted variant of the Riemannian conjugate gradient method are guaranteed to converge to the measured rank r matrix provided the number of measurements is proportional to nr^2 up to a log factor. Empirical evaluation shows that the algorithms are able to recover a low rank matrix from nearly the minimum number of measurements necessary. The extensions of the algorithms to low rank matrix demixing and the corresponding recovery guarantees will also be discussed.

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A new signature of quantum phase transitions from the numerical range

Predicting quantum phase transitions by signatures in finite models has a long tradition. Here we consider the numerical range W of a finite dimensional one-parameter Hamiltonian, which is a planar projection of the convex set of density matrices. We propose the new geometrical signature of non-analytic points of class C^2 on the boundary of W. We prove that a discontinuity of a maximum-entropy inference map occurs at these points, a pattern which was earlier fostered as a signature of quantum phase transitions. More precisely, we reduce both phenomena to higher energy level crossings with the ground state energy.

This is joint work with Ilya M. Spitkovsky, NYU Abu Dhabi, United Arab Emirates

A preprint with identical title will be available on the arXiv

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A generalization of skew adjacency matrices and spectra

Given an undirected graph and an orientation on the graph we can construct a skew adjacency matrix and a skew spectrum. By introducing a complex variable, we can generalize to the complex plane where we can instead create Hermitian matrices. With particular choices of the complex variable with can recover both information about the skew spectra and the standard adjacency spectrum. We will also talk about leaving the complex variable undetermined and averaging over all the possible orientations of the graph.

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Q-polynomial association schemes with at most 5 classes.

An association scheme can be thought of as a combinatorial generalization of a finite transitive permutation group, where the notion of global symmetry is replaced by certain local symmetry conditions. The definition of association scheme is due to Bose and Shimamoto in 1939, in the context of the design of experiments. Since then it has found connections to coding theory, group theory, and finite geometry.

In the 1973 thesis of Philippe Delsarte, the author identified two special classes of association schemes: the so-called P-polynomial and Q-polynomial schemes. The schemes that are P-polynomial are precisely those generated by a distance-regular graph, in which Delsarte gave natural analogues to coding theory. Similarly, Delsarte gave a natural analogue to design theory in Q-polynomial schemes.

However, Q-polynomial schemes have no analogous combinatorial definition. Consequently, much less is known about them then their P-polynomial counterparts. In this talk, we will discuss what is known about primitive 3-class Q-polynomial schemes, and imprimitive Q-polynomial schemes with at most 5 classes. We will also present new tables of parameter sets summarizing known constructions, non-existence results and open cases.

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Complete spectral sets and numerical range

We define the complete numerical radius norm for homomorphisms from any operator algebra into $\mathcal{B}(\mathcal{H})$, and show that this norm can be computed explicitly in terms of the completely bounded norm. This is used to show that if K is a complete C-spectral set for an operator T, then it is a complete M-numerical radius set, where $M = \frac{1}{2}(C + C^{-1})$. In particular, in view of Crouzeix's theorem, there is a universal constant M (less than 5.6) so that if P is a matrix polynomial and $T \in \mathcal{B}(\mathcal{H})$, then $w(P(T)) \leq M\|P\|_{W(T)}$. When $W(T) = \overline{\mathbb{D}}$, we have $M = \frac{5}{4}$.

This is joint work with Kenneth R. Davidson and Vern I. Paulsen.

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Computing Dense versus Sparse Equilibrium States for Evolutionary Games

The evolution of a population of social or biological species can be modeled as an evolutionary game with the equilibrium states of the game as predictions for the ultimate distributions of the species in the population, where some species may survive with positive proportions, while others extinct with zero proportions. We say a state is dense if it contains a large and diverse number of positive species, and is sparse if it contains only a few dominant ones. Sparse equilibrium states can be found relatively easily, while dense ones are more computationally costly. Here we show that by formulating a 'dual' problem for the computation of the equilibrium states, we are able to reduce the cost for computing dense equilibrium states and thereby obtain them much more efficiently.

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Pseudo-direct sums and wreath products of loose-coherent algebras with applications to coherent configurations

We introduce the notion of a loose-coherent algebra, which is a special semisimple subalgebra of the matrix algebra, and define two operations to obtain new loose-coherent algebras from the old ones: the pseudo-direct sum and the wreath product. For two arbitrary coherent configurations $\mathfrak{C}$, $\mathfrak{D}$ and their wreath product $\mathfrak{C} \wr \mathfrak{D}$, it is difficult to express the Terwilliger algebra $\mathcal{T}_{(x,y)}(\mathfrak{C} \wr \mathfrak{D})$ in terms of the Terwilliger algebras $\mathcal{T}_x(\mathfrak{C})$ and $\mathcal{T}_y(\mathfrak{D})$. By using the concept and operations of loose-coherent algebras, we obtain a very simple such expression. As a direct consequence of this expression, we get the central primitive idempotents of $\mathcal{T}_{(x,y)}(\mathfrak{C} \wr \mathfrak{D})$ in terms of the central primitive idempotents of $\mathcal{T}_x(\mathfrak{C})$ and $\mathcal{T}_y(\mathfrak{D})$. Many known results are special cases of the results in this paper.

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Properties of weighted operator means via generalized relative operator entropy

For positive definite matrices A and B, the relative operator entropy

$$S(A|B) = A^{1/2} \log(A^{-1/2}BA^{-1/2})A^{1/2}$$

can be considered as a derivative of $A\sharp_\alpha B$ at $\alpha = 0$. In this talk, firstly, we shall introduce generalized operator entropy which follows from any non-weighted operator means. Next, we shall introduce a weighted operator mean by using the generalized relative operator entropy, and introduce its properties.

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A recursion formula for resistance distances and its applications

Intrinsic metrics on a graph G have become of interest. Amongst these metrics are the common shortest-path metric, and also the 'resistance distance', for which there are different equivalent definitions including that this distance is the net effective resistance $\Omega(i,j)$ between $i, j \in V(G)$ when unit resistors are associated to each edge of G. And this net resistance is still a metric when there are different positive weights for the edges. In this guise the $\Omega(i,j)$ have long been studied, as a part of electrical circuit theory, dating back to Kirchhoff and Maxwell, and extending on to modern electrical engineering. In this talk, a recursion formula for resistance distances is obtained, and some of its applications are illustrated.

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Tensor network ranks

At the beginning of this talk, we will introduce the background of tensor network states (TNS) in various areas such as quantum physics, quantum chemistry and numerical partial differential equations. Famous TNS includes tensor trains (TT), matrix product states (MPS), projected entangled pair states (PEPS) and multi-scale entanglement renormalization ansatz (MERA). Then we will explain how to define TNS by graphs and we will define tensor network ranks which can be used to measure the complexity of TNS. We will see that the notion of tensor network ranks is an analogue of tensor rank and multilinear rank. We will discuss basic properties of tensor network ranks and the comparison among tensor network ranks, tensors rank and multilinear rank. If time permits, we will also discuss the dimension of tensor networks and the geometry of TNS. This talk is based on papers joined with Lek-Heng Lim.

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Remarks on two determinantal inequalities

Denote by $\mathcal{P}_n$ the set of $n \times n$ positive definite matrices. Let $D = D_1 \oplus \cdots \oplus D_k$, where $D_1 \in \mathcal{P}_{n_1}, \ldots, D_k \in \mathcal{P}_{n_k}$ with $n_1 + \cdots + n_k = n$. Partition $C \in \mathcal{P}_n$ according to $(n_1, \ldots, n_k)$ so that $\operatorname{diag} C = C_1 \oplus \cdots \oplus C_k$. For any $p \geq 0$, we have

$$\det(I_{n_1} + (C_1^{-1} D_1)^p) \cdots \det(I_{n_k} + (C_k^{-1} D_k)^p) \leq \det(I_n + (C^{-1} D)^p).$$

This is a generalization of a determinantal inequality of Matic [Theorem 1.1]. In addition, we obtain a weak majorization result which is complementary to a determinantal inequality of Choi [Theorem 2] and give a weak log majorization open question.

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Hadamard diagonalizable graphs used to transfer quantum information

Our work focuses on Hadamard diagonalizable graphs. For integer-weighted Hadamard diagonalizable graphs, we give an eigenvalue characterization of when such a graph exhibits perfect state transfer (PST) at time $\pi/2$, and then generalize the result to rational-weighted Hadamard diagonalizable graphs. We also define a new binary graph operation, the merge, which keeps the property of being Hadamard diagonalizable, and can be used to produce a lot of PST graphs. We give conditions on two integer-weighted Hadamard diagonalizable graphs for their merge to have PST. Finally we show an intriguing result about the merge operation: when exactly one of the two weights on this operation is an integer, and the other one is an irrational number, then the merge exhibits pretty good state transfer (PGST) from one vertex to several other vertices under certain circumstances. This is joint work with N. Johnston, S. Kirkland, S. Plosker, and R. Storey.

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Solving Ore matrix equations

Matrices with Ore polynomial entries have been studied theoretically in non-commutative algebra area at least from Jacobson's work in 1930's. Recently many applications, especially in control theory and solving differential/difference equations have been discovered. In this talk, we discuss solving some types of Ore matrix equations. Using Jacobson's normal form and generalized inverses, we can give the general (or explicit) solutions.

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Resistance distance and resistance matrix of graphs

For two vertices u, v in a connected G, the resistance distance between u and v, denoted by r_{uv}, is defined to be the effective resistance between them when unit resistors are placed on every edge of G. The resistance matrix of G is defined as $R = (r_{uv})$.

The resistance distance is a distance function on graphs, which has important applications in complex networks, random walks on graphs, and chemistry. In this talk, we report some recent results on resistance distance and resistance matrix of graphs, including formulas for the resistance distance, spectral properties of the resistance matrix, and some applications to spectral graph theory.