

# Shmuel Friedland

## Curriculum Vita

### Professional Preparation

Israel Institute of Technology	Mathematics, B.Sc., 1967
Israel Institute of Technology	Mathematics, M.Sc., 1969
Israel Institute of Technology	Mathematics, D.Sc., 1971
Israel Institute of Technology	Postdoc in Mathematics, 1971–72
Weizmann Institute of Science	Postdoc in Mathematics, 1972–73
Stanford University	Postdoc in Mathematics, 1973–74
IAS, Princeton	Postdoc in Mathematics, 1974–75

### Appointments

#### *Regular*

- 1985–present, Professor, University of Illinois at Chicago
- 1982–85, Professor, Institute of Mathematics, Hebrew University, Jerusalem, Israel, <http://www.ma.huji.ac.il/>
- 1978–82, Associate Professor, Hebrew University
- 1975–78, Senior Lecturer, Hebrew University

#### *Visiting*

- 2007–08, First Visiting Professor in Berlin Mathematical School, Berlin, Germany, <http://www.math-berlin.de/bms-faculty/guests>
- 2003–04, First New Directions Professor, IMA, University of Minnesota, supported by NSF, <http://www.ima.umn.edu/new-directions/#Past>
- 9/00–12/00, Lady Davis fellow, Technion, Israel, <http://ldft.huji.ac.il/>
- 1/94–6/94, Visiting Professor, IHES, France, <http://www.ihes.fr/jsp/site/Portal.jsp>
- 9/91–12/91, Visiting Professor, IMA, University of Minnesota
- 9/89–3/90, Visiting Professor, Northwestern University
- 9/78–8/80, Visiting Professor, University of Wisconsin

### Prizes

- The first Hans Schneider prize in Linear Algebra awarded by ILAS (International Linear Algebra Society) in 1993, <http://www.ilasic.org/misc/hsall.html>
- Salmon prize for solution of the set-theoretic version of the Salmon Conjecture posed by E.A. Allman 2010, <http://www.dms.uaf.edu/~eallman/>

## Areas of research

- Algebra, Algebraic Geometry, Applied Mathematics, Combinatorics, Functions of Complex Variables, Dynamical Systems, Ergodic Theory, Mathematical Biology, Mathematical Physics, Matrices, Probability, Quantum Information Theory, Tensors.

## Short account of major works

- My first area of research was coefficient problems in univalent functions. The major open problem was the Bieberbach conjecture. In my master thesis I proved the Robertson conjecture for  $n = 4$  [MR0255796-1970], which implies the case  $n = 4$  of the Bieberbach conjecture, proved by Garabedian and Schiffer. The Bieberbach conjecture was proved by de Branges in 1985. Together with Aharonov we proved the coefficient conjecture for functions of bounded boundary rotation [MR0322155-1972]. Together with Schiffer we combined the methods of optimal control to study the coefficient problems in univalent functions [MR0507756-1977].

My second area of my research, which turned out to be the major area of my research, is linear algebra, matrices and their extensions to operator theory. For these work I won the first Hans Schneider Prize in 1993, now widely regarded as the highest honor in Linear Algebra. In my joint paper with Karlin, in *Duke Math. J.*, we characterized the spectral radius of nonnegative matrices [MR0376717-1975]. This result found many applications in both pure and applied mathematics. Together with Hayman we wrote a seminal paper on the eigenvalue inequalities for the Dirichlet problems on spheres [MR0412442-1976]. In my paper on inverse eigenvalue problems I introduced the methods of topology and algebraic geometry to the inverse eigenvalue problems [MR0472861-1977]. Together with Nokedal and Overton we continued the theoretical and numerical aspects of inverse eigenvalue problems in [MR0888754-1987]. My paper on the inverse eigenvalue problem for symmetric Toeplitz matrices [MR1182718-1992] laid the foundation for of Landau's paper [MR1234570-1994] on the Toeplitz matrix in *J. Amer. Math. Soc.*. My seminal paper on inverse eigenvalue problem for nonnegative and eventually nonnegative matrices [MR0492634-1978] provided essential foundation for the *Annals* paper of Boyle and Handelmann on the nonnegative matrix [MR1097240-1991]. My *Annals* article [MR0541335-1979] on the permanent of doubly stochastic matrices laid a cornerstone that led to the resolution of van der Waerden conjecture. In [MR0650725-1982] I proved the generalized van der Waerden conjecture, called Tverberg's conjecture. Together with J. Robbin and J. Sylvester [MR0728265-1984] we solved Peter Lax's famous problem on the von Neumann–Wigner crossing rule, which appeared in *Comm. Pure Appl. Math.* (Together with Barry Simon we started to study the related problem of degenerate matrix pencils in [MR0657697-1982].) In [MR0682831-1983, MR0724475-1983] I resolved the notoriously difficult problem of classifying matrices up to simultaneous similarity. Together with Noga Alon and Gil Kalai we generalized Olson's theorem to obtain sufficient conditions for a graph to contain regular spanning subgraphs [MR0762897-1984, MR0762898-1984]. In joint work with John Milnor [MR0991490-1989] we uncovered important dynamical properties of plane polynomial automorphisms.

## Short account of major works (continued)

- This led to further work that relates the entropy of a rational map to the spectral radius of its induced linear action on the homology groups, another masterpiece in the Annals [MR1097242-1991]. In joint Duke paper with Hersonsky [MR1208812-1993] we proposed a vast extension of Martin's Acta paper on Jørgensen's inequality [MR1032075-1989] to discrete multiplicative subgroups in normed unital algebras. In my seminal papers on entropies of algebraic maps, graphs, semigroups and groups [MR1364887-1995, MR1411226-1996] I study various notions of entropy and inequalities that they satisfy. In particular, I defined what is known as Friedland's entropy. In solo papers and joint papers with Uri Peled we studied the entropy, associated pressure and phase transition of  $Z^d$ -subshifts of finite type [MR1428636-1997, MR2043239-2003, MR2122054-2004, MR2123547-2005, MR3051167-2011]. The papers [MR1738583-1999, MR1839864-2001] summarize my approach to the notorious difficult Jacobian conjecture. In [MR1799621-2000] I give finite and infinite dimensional generalizations of Kyachko's theorem. Jointly with Rider and Zeitouni we give in [MR2071434-2004] concentration of permanent estimators for certain large matrices. Jointly with Kim, Peled, and Pless we give in [MR2097054-2004] explicit constructions of families of LDPC codes with no 4-cycles. Jointly with Benji Weiss we treat in [MR2152469-2005] the famous Furstenberg 2 – 3 conjecture. In joint papers with Gurvits, Krop, Lundow, Markstrom and Federbush we study the matching in regular bipartite graphs and their asymptotic versions for the monomer-dimer models [MR2410392-2008, MR2438582-2008, MR2448634-2008, MR2793167-2011]. In my solo paper [MR2996364-2013] and the joint paper with my Ph.D. student E. Gross [MR2891138-2012] we proved the set theoretical version of the 'Salmon Conjecture' posed by Allman [MR2388607-2008], regarding the defining equations of the 4th secant variety of  $4 \times 4 \times 4$  tensors, a problem with important consequences in phylogenetics whose proof eluded algebraic geometers for many years. In the seminal work with Stephan Gaubert and Lixing Han we gave in [MR2996365-2013] generalizations of the famous Perron-Frobenius theorem to nonnegative multilinear forms. Jointly with Ottaviani we gave in [MR3273677-2014] an exact formula for a generic number of singular values of tensors. The special case of this sequence for 3-tensors  $(n, n, n)$  appears as Friedland-Ottaviani sequence in the On-Line Encyclopedia of Integer Sequences by N.J.A. Sloane. Jointly with Gilad Gour and collaborators we made a contribution to the theory of quantum channels [MR2839067-2011], [MR2839067-2013] and uncertainty principle [Phys. Rev. Lett. 111, 230401]. Jointly with L.-H. Lim we show in [MR3566920-2016] the fundamental theorem on the equivalence of computation in polynomial time of a norm and its dual. My recent book *Matrices: Algebra, Analysis and Applications*, World Scientific, 596 pp., 2015, Singapore [MR3467205-2016] summarizes a major part of my work on matrices. Jointly with L.-H. Lim we show in [MR3566920-2016] the fundamental theorem on polynomial equivalence of computation of a norm and its dual.
- A vivid account of some parts of my research can be found in my interview by Lek-Heng Lim for the IMAGE issue of ILAS (The Bulletin of the International Linear Algebra Society) <https://www.stat.uchicago.edu/~lekheng/work/friedland.pdf>

## Distinguished collaborators

- Noga Alon (Erdős Prize, Feher prize, Pólya Prize, Bruno Memorial Award, Landau Prize, Gödel Prize, Israel Prize, Emet Prize), Carl de Boer (National Academy of Sciences, American Academy of Arts and Sciences, National Academy of Engineering, German Academy of Sciences, Polish Academy of Science, National Medal of Science, von Neumann Prize, Gregory Award of Geometric Design), Joel E. Cohen (MacArthur Foundation Fellow, National Academy of Sciences), Walter K. Hayman (Fellow of the Royal Society, the Finnish Academy of Science and Letters, "Foreign member" of the Accademia dei Lincei, De Morgan Medal), Gil Kalai (Fulkerson Prize, Pólya Prize, Academia Europaea), Samuel Karlin (National Medal of Science, Member of National Academy of Science), Tosio Kato (Wiener Prize in Applied Mathematics), Frank Kelly ( Guy Medal, von Neumann Theory Prize, Rollo Davidson Prize, Commander of the Order of the British Empire, Fellow of the Royal Society), John Milnor (Fields Medal, National Medal of Science, Ford Award, Leroy P Steele Prize, Wolf Prize, Abel Prize), N. Moiseyev (Medal of Centre de Mecanique Ondulatoire Appliquee founded by Louis de Broglie, Landau Prize for Sciences and Research in physical chemistry, Humboldt award), Zeev Nehari (Nehari manifold), Jorge Nocedal (Dantzig Prize, Broyden Prize), Menahem Max Schiffer (A leading mathematician in 20th century, <http://www-history.mcs.st-andrews.ac.uk/Biographies/Schiffer.html>) Barry Simon (Poincaré Prize, Bolyai Prize).

## Publications

- Published 200+ research papers. (See the list of publications.)
- Google citation index: above 5,000. Mathematics Review citation index: above 1,400.
- Book: *Matrices: Algebra, Analysis and Applications*, World Scientific, 596 pp., December 2015, [www.worldscientific.com/worldscibooks/10.1142/9567](http://www.worldscientific.com/worldscibooks/10.1142/9567)  
This volume deals with advanced topics in matrix theory using the notions and tools from algebra, analysis, geometry and numerical analysis. It consists of seven chapters that are loosely connected and interdependent. This book summarize a good part of Friedland's research in matrix theory.
- Book: *Linear Algebra and Matrices*, (jointly with M. Aliabadi), SIAM, to appear in 2018. An advanced second undergraduate course, and beginning graduate in Linear Algebra.
- Top cited paper 2005-2010 in the journal "Advances in Applied Mathematics" for the joint paper with U. Peled: Theory of Computation of Multidimensional Entropy with an Application to the Monomer-Dimer Problem, *Advances of Applied Math.* 34(2005), 486-522, <http://www2.math.uic.edu/friedlan/friedlan/mstcitpapFP05.pdf>

## Publications (continued)

- List of the the significant journals Friedland's papers appeared with their *2014 Impact Factor*: Advances in Applied Mathematics (0.82), Advances in Mathematics (1.294), Annals of Applied Probability (1.454), Annals of Mathematics (3.236), Archive for Rational Mechanics and Analysis (2.219), Bulletin of the American Mathematical Society (2.107), Commentarii Mathematici Helvetici (0.938), Communications in Pure and Applied Mathematics (3.130), Compositio Mathematica (0.993), Discrete Applied Mathematics (0.802), Duke Mathematical Journal (1.578), Foundations of Computational Mathematics (2.389), IEEE Journal on Selected Areas in Communications (3.453), IEEE Transactions on Image Processing (3.625), IEEE Transactions on Information Theory (2.326), Israel Journal Of Mathematics (0.787), Journal d'Analyse Mathématique (0.977), Journal of Chemical Physics (2.952), Journal of Combinatorial Theory Series B (0.983), Journal of Ergodic Theory & Dynamical Systems (0.778), Journal of Fourier Analysis and Applications (1.118), Journal of Functional Analysis (1.322), Journal of Mathematical Analysis and Applications (1.12), Journal of Mathematical Physics (1.243), Journal of Multivariate Analysis (0.934), Journal of Optimization Theory and Applications (1.509), Journal of Statistical Physics (1.202), Linear Algebra and its Applications (0.939), Mathematics of Computation (1.881) Memoirs of the American Mathematical Society (1.727), Numerical Linear Algebra with Applications (1.322), Quantum information & computation (1.393), Physical Review A (2.808), Physical Review Letters (7.512), SIAM Journal on Mathematical Analysis (1.265), SIAM Journal on Matrix Analysis and Applications (1.59), SIAM Journal on Numerical Analysis (1.788), SIAM Journal on Optimization (1.968), Transactions of the American Mathematical Society (1.122).

## Graduate students and Post doctoral scholars

- Graduate Students: Pedro Jorge Freitas, 1999, Gaspar Porta, 1999, Amir Niknejad, 2005, Elliot J. Krop, 2007, Mechie Nkengla 2010, Elizabeth Gross (received an NSF postdoc) 2013, Samuel Cole, Mohsen Aliabadi.
- Postdocs: Afshin Behmaram, Li Wang.

## New developed undergraduate and graduate courses

- An algorithmic theory of numbers and graphs.
- Combinatorial optimization.
- Freshman seminar: How to gamble if you must.
- Introduction to quantum information theory.
- Probability on graphs
- Tensors
- Topics in matrix theory.

## Synergistic Activities

- Editorial Board: Linear Algebra and Its Applications, Linear and Multilinear Algebra, Electronic Journal of Linear Algebra, Special Matrices.

## Grants

- BSF (Binational Science Foundation) grants late 1970 and early 1980's in Israel.
- Several NSF grants in late 1980's and beginning 1990's in Matrix Theory
- NSF grant in Computational Mathematics: 2012-2016.

## Member of prize committees

- A member of the Householder prize committee 1984.
- A member of the Hans Schneider prize committee a number of times.

## Selected national and international lectures last 8 years

- Invited speaker in "International Workshop on Quantum Computation and Cryptanalysis" (QCCA 2017), organized by the Academy of Mathematics and Systems Science of the Chinese Academy of Sciences, Beijing, China November 1-3, 2017.
- Invited speaker in Minisymposium: Tensors: from Algebra to Applications, 2017 SIAM Conference on Applied Algebraic Geometry, July 31 - August 4, Atlanta.
- Invited speaker in Numerical Linear Algebra Workshop, FoCM 2017 Foundations of Computational Mathematics, Barcelona, July 10th-19th, 2017.
- Invited conference speaker, The Third International Conference on Engineering and Computational Mathematics (ECM2017), The Hong Kong Polytechnic University, May 31 - June 2, 2017.
- Invited conference speaker, 2016 International Conference on Tensors, Matrices and Their Applications, May 21-24, 2016, Chern Math Research Institute at Nankai University, Tianjin, China.
- Plenary speaker of 2016 International Workshop on Tensor and Matrix with Applications (IWTMA), 18-19 May, 2016, Department of Mathematics, University of Shanghai, China.
- Invited speaker, Workshop on Tensor Decompositions and Applications January 18 - 22, 2016, Leuven, Belgium
- Keynote Speaker of the 5th International Conference on Matrices and Applications (ICMA), Dec. 18-20, 2015, Fort Lauderdale, Florida, USA.
- Invited conference speaker, "Numerical Algebra, Matrix Theory, Differential-Algebraic Equations, and Control Theory" in honor of Volker Mehrmann 60, 6-9 May 2015, TU Berlin, Berlin, Germany.
- Invited lecturer, workshop Tensors in Computer Science and Geometry, the Simons Institute at Berkeley, November 10-14, 2014.

## Selected national and international lectures last 8 years (continued)

- Invited lecturer, AIM workshop: Positivity, graphical models, and modeling of complex multivariate dependencies, American Institute of Mathematics, Palo Alto, CA, October 13 - 17, 2014.
- Invited lecturer, Computational Problems in Tensors, workshop in Computational Nonlinear Algebra, ICERM, Brown University, June 2-6, 2014.
- Colloquium lecture, Best approximation by algebraic and semi-algebraic sets, Colloquium, Courant Institute of Mathematical Sciences, New York University, May 12, 2014.
- Invited conference speaker, The International Conference on Engineering and Computational Mathematics, The Hong-Kong Polytechnic University, December 17, 2013.
- Invited speaker, Matheon-Workshop Compressed Sensing and its Applications, Berlin, Germany, December 11, 2013.
- Invited conference speaker, Conference in honor of Rajendra Bhatia, Bangalore, India, December 28, 2012.
- Invited conference speaker, Conference in honor of Singhi, Tata Institute of fundamental research, Mumbai, India, December 18, 2012.
- Conference speaker, 2012 Haifa Matrix Theory Conference, Technion, Haifa, Israel, November 13, 2012.
- Conference speaker, International Conference on the spectral theory of the tensor, Chern Institute, Nankai University, Tianjin, China, May 31, 2012.
- Invited speaker, AIM workshop: Stability, hyperbolicity, and zero localization of functions, American Institute of Mathematics, Palo Alto, CA, December 7, 2011.
- Invited conference speaker, Conference on matrices and combinatorics, Coimbra University, Portugal, July 9, 2011.
- Invited speaker, Summer School is supported by CMUC - Centre for Mathematics, University of Coimbra, Coimbra, Portugal. Six lectures of 90 minutes each from July 6 to July 8, 2011.
- Invited conference speaker, Tropical Mathematics and its Applications, Meeting of the London Mathematical Society, Joint Research Group, Birmingham, England, June 28, 2011.
- Invited conference speaker, Householder Symposium XVIII, Tahoe City, California, June 13, 2011.
- Invited conference speaker, Linear Algebraic Techniques in Combinatorics/Graph Theory, Banff International Research Station for Mathematical Innovation and Discovery, in Banff, Alberta, Canada, February 1, 2011.
- Invited speaker, JRI Workshop on eigenvalues of nonnegative tensors, Department of Applied mathematics, The Hong Kong Polytechnic University. Hong-Kong, December 18, 2010.
- Colloquium speaker, Colloquium, Department of Computer Science, City University of Hong-Kong, December 14, 2010.
- Keynote address, 2010 Western Canada Linear Algebra Meeting (WCLAM), Banff International Research Station, May 8, 2010.
- Invited speaker, Workshop in Graph Theory and Combinatorics in Memory of Uri Peled, Department of Mathematics, UIC, February 21, 2010.

## Selected national and international lectures last 8 years (continued)

- Colloquium speaker, Tata Institute of Fundamental Research, School of Mathematics, December 17, 2009.
- Invited conference speaker, LINEAR AND NUMERICAL LINEAR ALGEBRA: THEORY, METHODS, and APPLICATIONS, Northern Illinois University, August 12, 2009.
- Invited conference speaker, 2009 Haifa Matrix Theory Conference, Haifa, Israel, May 20, 2009.
- Colloquium speaker, Center for Applied Mathematics, University of Notre Dame, Indiana, April 7, 2009.
- Colloquium speaker, University of British Columbia, Canada, University of British Columbia, Canada, March 6, 2009.