# Biographical Sketch: Shmuel Friedland

### 1. PROFESSIONAL PREPARATION

- Technion Israel Institute of Technology: B.Sc., 1967; M.Sc., 1969; D.Sc., 1971
- Weizmann Institute of Science: Postdoc in Mathematics, 1972–73
- Stanford University: Instructor in Mathematics, 1973–74
- Institute for Advanced Studies (IAS), Princeton: Member, 1974–75

### 2. APPOINTMENTS

- Hebrew University: Senior Lecturer, 1975–78; Associate Professor, 1978–82; Professor, 1982–85
- University of Illinois at Chicago: Professor, 1985–2018; Professor Emeritus, 2018–

### 3. VISITING APPOINTMENTS

- University of Wisconsin, Madison: Visiting Professor, 9/1978–8/1980
- Northwestern University: Visiting Professor, 9/1989–3/1990
- Institut des Hautes Études Scientifiques (IHES), France: Visiting Professor, 1/1994–6/1994
- Technion Israel Institute of Technology: Lady Davis Fellow, 9/2000–12/2000
- University of Minnesota, Minneapolis, Institute of Mathematics and its Applications (IMA): Visiting Professor, 9/1991–12/1991; New Directions Professor, 9/2003–8/2004
- Berlin Mathematical School, Germany: BMS Professor, 8/2007–7/2008

### 4. SELECTED HONORS

- First Hans Schneider Prize of the International Linear Algebra Society, 1993
- Salmon Prize for solving Elizabeth Allman's Salmon Conjecture, 2010
- Fellow of the American Mathematical Society, 2019
- Fellow of the Society for Industrial and Applied Mathematics, 2021

### 5. SELECTED PROFESSIONAL ACTIVITIES

- Member of editorial boards: Linear Algebra and Its Applications, Linear and Multilinear Algebra, Electronic Journal of Linear Algebra, Special Matrices
- Member of the committee for the Alston Householder Prize in Numerical Linear Algebra, 1984
- Member of the committee for the Hans Schneider Prize in Linear Algebra, 1996, 2012, 2015, 2018
- Ph.D. students: Pedro Jorge Freitas, 1999; Gaspar Porta, 1999; Amir Niknejad, 2005; Elliot J. Krop, 2007; Mechie Nkengla, 2010; Elizabeth Gross, 2013; Samuel Cole, 2018; Mohsen Aliabadi 2020
- Postdocs: Afshin Behmaram, Li Wang

### 6. SELECTED PUBLICATIONS

- 226 journal publications, two books
- Citations: around 2,000 on Mathematical Reviews, 7,000 on Google Scholar

**Representative publications:**

[1] S. Friedland, "A lower bound for the permanent of a doubly stochastic matrix," *Ann. of Math.*, **110** (1979), no. 1, pp. 167–176.

[2] S. Friedland, "Entropy of polynomial and rational maps," *Ann. of Math.*, **133** (1991), no. 2, pp. 359–368.

[3] S. Friedland, "Nonoscillation and integral inequalities," *Bull. Amer. Math. Soc.*, **80** (1974), no. 4, pp. 715–717.

[4] S. Friedland, "Nonoscillation, disconjugacy and integral inequalities," *Mem. Amer. Math. Soc.*, **7** (1976), no. 176, v+78 pp.

[5] S. Friedland, "Simultaneous similarity of matrices," *Bull. Amer. Math. Soc.*, **8** (1983), no. 1, pp. 93–95.

[6] S. Friedland, "Simultaneous similarity of matrices," *Adv. Math.*, **50** (1983), no. 3, pp. 189–265.

[7] S. Friedland, S. Hersonsky, "Jorgensen's inequality for discrete groups in normed algebras," *Duke Math. J.*, **69** (1993), no. 3, pp. 593–614.

[8] S. Friedland, S. Karlin, "Some inequalities for the spectral radius of non-negative matrices and applications," *Duke Math. J.*, **42** (1975), no. 3, pp. 459–490.

[9] S. Friedland, J. Milnor, "Dynamical properties of plane polynomial automorphisms," *Ergodic Theory Dynam. Systems*, **9** (1989), no. 1, pp. 67–99.

[10] S. Friedland, P. Nowosad, "Extremal eigenvalue problems with indefinite kernels," *Adv. in Math.*, **40** (1981), no. 2, pp. 128–154.

[11] S. Friedland, J. W. Robbin, J. H. Sylvester, "On the crossing rule," *Comm. Pure Appl. Math.*, **37** (1984), no. 1, pp. 19–37.

[12] S. Friedland, M. Schiffer, "Global results in control theory with applications to univalent functions," *Bull. Amer. Math. Soc.*, **82** (1976), no. 6, pp. 913–915.

**Combinatorics:**

[13] N. Alon, S. Friedland, "The maximum number of perfect matchings in graphs with a given degree sequence," *Electron. J. Combin.*, **15** (2008), no. 1, Note 13, 2 pp.

[14] N. Alon, S. Friedland, G. Kalai, "Every 4-regular graph plus an edge contains a 3-regular subgraph," *J. Combin. Theory Ser. B*, **37** (1984), no. 1, pp. 92–93.

[15] N. Alon, S. Friedland, G. Kalai, "Regular subgraphs of almost regular graphs," *J. Combin. Theory Ser. B*, **37** (1984), no. 1, p. 79–91.

[16] S. Friedland, "Every 7-regular digraph contains an even cycle," *J. Combin. Theory Ser. B*, **46** (1989), no. 2, pp. 249–252.

[17] S. Friedland, L. Gurvits, "Lower bounds for partial matchings in regular bipartite graphs and applications to the monomer-dimer entropy," *Combin. Probab. Comput.*, **17** (2008), no. 3, pp. 347–361.

[18] S. Friedland, E. Krop, K. Markström, "On the number of matchings in regular graphs," *Electron. J. Combin.*, **15** (2008), no. 1, Research Paper 110, 28 pp.

**Dynamical systems:**

[19] S. Friedland, "Entropy of algebraic maps," Proceedings of the Conference in Honor of Jean-Pierre Kahane, *J. Fourier Anal. Appl.*, Special Issue (1995), pp. 215–228.

[20] S. Friedland, "Entropy of graphs, semigroups and groups," *Ergodic Theory of $\mathbf{Z}^d$ Actions*, pp. 319–343, London Math. Soc. Lecture Note Ser., **228**, Cambridge University Press, Cambridge, 1996.

[21] S. Friedland, "Invariant measures of groups of homeomorphisms and Auslander's conjecture," *Ergodic Theory Dynam. Systems*, **15** (1995), no. 6, pp. 1075–1089.

[22] S. Friedland, "On the entropy of $\mathbf{Z}^d$ subshifts of finite type," *Linear Algebra Appl.*, **252** (1997), no. 1–3, pp. 199–220.

[23] S. Friedland, U. N. Peled, "The pressure, densities and first-order phase transitions associated with multidimensional SOFT," *Notions of positivity and the geometry of polynomials*, pp. 179–220, Trends Math., Birkhäuser, Basel, 2011.

[24] S. Friedland, U. N. Peled, "Theory of computation of multidimensional entropy with an application to the monomer-dimer problem," *Adv. in Appl. Math.*, **34** (2005), no. 3, pp. 486–522.

[25] S. Friedland, B. Weiss, "Generalized interval exchanges and the 2-3 conjecture," *Cent. Eur. J. Math.*, **3** (2005), no. 3, pp. 412–429.

**Matrix theory:**

[26] J. E. Cohen, S. Friedland, T. Kato, F. P. Kelly, "Eigenvalue inequalities for products of matrix exponentials," *Linear Algebra Appl.*, **45** (1982), pp. 55–95.

[27] C. de Boor, S. Friedland, A. Pinkus, "Inverses of infinite sign regular matrices," *Trans. Amer. Math. Soc.*, **274** (1982), no. 1, pp. 59–68.

[28] D. Falikman, S. Friedland, R. Loewy, "On spaces of matrices containing a nonzero matrix of bounded rank," *Pacific J. Math.*, **207** (2002), no. 1, pp. 157–176.

[29] S. Friedland, "A proof of a generalized van der Waerden conjecture on permanents," *Linear Multilinear Algebra*, **11** (1982), no. 2, pp. 107–120.

[30] S. Friedland, "Inverse eigenvalue problems," *Linear Algebra Appl.*, **17** (1977), no. 1, pp. 15–51.

[31] S. Friedland, "Inverse eigenvalue problems for symmetric Toeplitz matrices," *SIAM J. Matrix Anal. Appl.*, **13** (1992), no. 4, pp. 1142–1153.

[32] S. Friedland, "On an inverse problem for nonnegative and eventually nonnegative matrices," *Israel J. Math.*, **29** (1978), no. 1, pp. 43–60.

[33] S. Friedland, D. Hershkowitz, H. Schneider, "Matrices whose powers are $M$-matrices or $Z$-matrices," *Trans. Amer. Math. Soc.*, **300** (1987), no. 1, pp. 343–366.

[34] S. Friedland, R. Loewy, "Subspaces of symmetric matrices containing matrices with a multiple first eigenvalue," *Pacific J. Math.*, **62** (1976), no. 2, pp. 389–399.

[35] S. Friedland, B. Rider, O. Zeitouni, "Concentration of permanent estimators for certain large matrices," *Ann. Appl. Probab.*, **14** (2004), no. 3, pp. 1559–1576.

[36] S. Friedland, B. Simon, "The codimension of degenerate pencils," *Linear Algebra Appl.*, **44** (1982), pp. 41–53.

## Mathematical physics:

[37] P. Federbush, S. Friedland, "An asymptotic expansion and recursive inequalities for the monomer-dimer problem," *J. Stat. Phys.*, **143** (2011), no. 2, pp. 306–325.

[38] S. Friedland, V. Gheorghiu, G. Gour, "Universal uncertainty relations," *Phys. Rev. Lett.*, **111** (2013), pp. 230401-1–4.

[39] S. Friedland, C.-K. Li, Y.-T. Poon, N.-S. Sze, "The automorphism group of separable states in quantum information theory," *J. Math. Phys.*, **52** (2011), no. 4, 042203, 8 pp.

[40] N. Moiseyev, S. Friedland, "Association of resonance states with the incomplete spectrum of finite complex-scaled Hamiltonian matrices," *Phys. Rev. A*, **22** (1980), no. 2, pp. 618–624.

[41] N. Moiseyev, S. Friedland, P. R. Certain, "Cusps, $\theta$ trajectories, and the complex virial theorem," *J. Chem. Phys.*, **74** (1981), no. 8, pp. 4739–4740.

[42] S. Friedland, T. Kemp, "Most boson quantum states are almost maximally entangled," *Proc. Amer. Math. Soc.*, **146** (2018), no. 12, pp. 5035–5049.

[43] S. Friedland, G. Gour, "An explicit expression for the relative entropy of entanglement in all dimensions," *J. Math. Phys.*, **52** (2011), no. 5, 052201, 13 pp.

[44] S. Friedland, G. Gour, A. Roy, "Local extrema of entropy functions under tensor products," *Quantum Inf. Comput.*, **11** (2011), no. 11–12, pp. 1028–1044.

[45] G. Gour, S. Friedland, "The minimum entropy output of a quantum channel is locally additive," *IEEE Trans. Inform. Theory*, **59** (2013), no. 1, pp. 603–614.

## Operator theory:

[46] S. Friedland, "A characterization of normal operators," *Israel J. Math.*, **42** (1982), no. 3, pp. 235–240.

[47] S. Friedland, "Characterizations of spectral radius of positive operators on $C^*$ algebras," *J. Funct. Anal.*, **97** (1991), no. 1, pp. 6470.

[48] S. Friedland, "Extremal eigenvalue problems for convex sets of symmetric matrices and operators," *Israel J. Math.*, **15** (1973), pp. 311–331.

[49] S. Friedland, G. Porta, "The limit of the product of the parameterized exponentials of two operators," *J. Funct. Anal.*, **210** (2004), no. 2, pp. 436–464.

## Tensors:

[50] R. A. Brualdi, S. Friedland, A. Pothen, "The sparse basis problem and multilinear algebra," *SIAM J. Matrix Anal. Appl.*, **16** (1995), no. 1, pp. 1–20.

[51] S. Friedland, S. Gaubert, L. Han, "Perron–Frobenius theorem for nonnegative multilinear forms and extensions," *Linear Algebra Appl.*, **438** (2013), no. 2, pp. 738–749.

[52] S. Friedland, E. Gross, "A proof of the set-theoretic version of the salmon conjecture," *J. Algebra*, **356** (2012), pp. 374–379.

[53] S. Friedland, L.-H. Lim, "Nuclear norm of higher-order tensors," *Math. Comp.*, **87** (2018), no. 311, pp. 1255–1281.

[54] S. Friedland, G. Ottaviani, "The number of singular vector tuples and uniqueness of best rank-one approximation of tensors," *Found. Comput. Math.*, **14** (2014), no. 6, pp. 1209–1242.

[55] S. Friedland, L. Wang, "Spectral norm of a symmetric tensor and its computation," *Math. Comp.*, **89** (2020), no. 325, pp. 2175–2215.

## Analysis, geometry, and topology:

[56] D. Aharonov, S. Friedland, "On an inequality connected with the coefficient conjecture for functions of bounded boundary rotations," *Ann. Acad. Sci. Fenn. A I*, no. 524 (1972), 14 pp.

[57] M. A. Berger, S. Friedland, "The generalized Radon–Hurwitz numbers," *Compositio Math.*, **59** (1986), no. 1, pp. 113–146.

[58] S. Friedland, "Extremal eigenvalue problems defined on conformal classes of compact Riemannian manifolds," *Comment. Math. Helv.*, **54** (1979), no. 3, pp. 494–507.

[59] S. Friedland, "On a conjecture of Robertson," *Arch. Rational Mech. Anal.*, **37** (1970), no. 4, pp. 255–261.

[60] S. Friedland, W. K. Hayman, "Eigenvalue inequalities for the Dirichlet problem on spheres and the growth of subharmonic functions," *Comment. Math. Helv.*, **51** (1976), no. 2, pp. 133–161.

[61] S. Friedland, M. Schiffer, "On coefficient regions of univalent functions," *J. Analyse Math.*, **31** (1977), no. 1, pp. 125–168.

### Computations:

[62] S. Friedland, L.-H. Lim, "The computational complexity of duality," *SIAM J. Optim.*, **26** (2016), no. 4, pp. 2378–2393.

[63] S. Friedland, L.-H. Lim, J. Zhang, "Grothendieck constant is norm of Strassen matrix multiplication tensor," *Numer. Math.*, **143** (2019), no. 4, pp. 905–922.

[64] S. Friedland, C. A. Micchelli, "Bounds on the solutions of difference equations and spline interpolation at knots," *Linear Algebra Appl.*, **20** (1978), no. 3, pp. 219–251.

[65] S. Friedland, J. Nocedal, M. L. Overton, "The formulation and analysis of numerical methods for inverse eigenvalue problems," *SIAM J. Numer. Anal.*, **24** (1987), no. 3, pp. 634–667.

[66] S. Friedland, E. Tadmor, "Optimality of the Lax–Wendroff condition," *Linear Algebra Appl.*, **56** (1984), pp. 121–129.

### Applications:

[67] S. Friedland, Q. Li, D. Schonfeld, "Compressive sensing of sparse tensors," *IEEE Trans. Image Process.*, **23** (2014), no. 10, pp. 4438–4447.

[68] S. Friedland, P. H. Lundow, K. Markström, "The 1-vertex transfer matrix and accurate estimation of channel capacity," *IEEE Trans. Inform. Theory*, **56** (2010), no. 8, pp. 3692–3699.

[69] S. Friedland, A. Niknejad, L. Chihara, "A simultaneous reconstruction of missing data in DNA microarrays," *Linear Algebra Appl.*, **416** (2006), no. 1, pp. 8–28.

[70] J.-L. Kim, U. N. Peled, I. Perepelitsa, V. Pless, S. Friedland, "Explicit construction of families of LDPC codes with no 4-cycles," *IEEE Trans. Inform. Theory*, **50** (2004), no. 10, pp. 2378–2388.

### Books:

[71] M. Aliabadi, S. Friedland, *Linear Algebra and Matrices*, SIAM, 293 pp., 2018.

[72] S. Friedland, *Matrices: Algebra, Analysis and Applications*, World Scientific, 596 pp., 2015.

## 7. Selected invited lectures past ten years

- Invited speaker, Meeting of the London Mathematical Society, Birmingham, England, 2011
- Invited lecturer, Six 90-minute Lectures on Matrices and Tensors, Coimbra, Portugal, 2011
- Invited speaker, Haifa Matrix Theory Conference, Haifa, Israel, 2012
- Invited speaker, Conference in honor of Rajendra Bhatia, Bangalore, India, 2012
- Invited speaker, MATHEON Workshop on Compressed Sensing and its Applications, Berlin, Germany, 2013
- Colloquium speaker, Courant Institute of Mathematical Sciences, New York, NY, 2014
- Invited lecturer, Workshop on Computational Nonlinear Algebra, Institute for Computational and Experimental Research in Mathematics (ICERM), 2014
- Invited speaker, Workshop on Positivity, Graphical Models, and Modeling of Complex Multivariate Dependencies, American Institute of Mathematics (AIM), Palo Alto, CA, 2014
- Invited lecturer, Program on Tensors in Computer Science and Geometry, Simons Institute, Berkeley, CA, 2014
- Invited speaker, Festschrift in Honor of Volker Mehrmann, Berlin, Germany, 2015
- Keynote speaker, 5th International Conference on Matrices and Applications, Fort Lauderdale, Florida, 2015
- Invited speaker, Workshop on Tensor Decompositions and Applications, Leuven, Belgium, 2016
- Plenary speaker, International Workshop on Tensor and Matrix with Applications, Shanghai, China, 2016
- Invited speaker, 8th International Conference on Matrix Analysis and Applications, Reno, NV, 2019
- ILAS lecturer, MAT TRIAD 2019, Liblice, Czech Republic, 2019
- One-hour speaker, AMS Sectional Meeting at Charlottesville, VA, 2020

- Invited speaker, 6th Workshop on Algebraic Designs, Hadamard Matrices, and Quanta, Krákow, Poland, 2021
- LAMA lecturer, 23rd International Linear Algebra Society Meeting, Galway, Ireland, 2022