

References

- [1] C. H. Ahn, W. C. Chew, J. S. Zhao, and E. Michielssen. Numerical study of approximate inverse preconditioner for two-dimensional engine inlet problems. *Electromagnetics*, 19(2):131–146, 1999.
- [2] M. A. Ajiz and A. Jennings. A robust incomplete Choleski-conjugate gradient algorithm. *Int. J. Numer. Methods Eng.*, 20(5):949–966, 1984.
- [3] G. Alléon, M. Benzi, and L. Giraud. Sparse approximate inverse preconditioning for dense linear systems arising in computational electromagnetics. *Numer. Algorithms*, 16(1):1–15, 1997.
- [4] P. R. Amestoy, T. A. Davis, and I. S. Duff. An approximate minimum degree ordering algorithm. *SIAM J. Matrix Anal. Appl.*, 17(4):886–905, 1996.
- [5] M. Arioli and G. Manzini. Null space algorithm and spanning trees in solving Darcy’s equation. *BIT*, 43(5):839–848, 2003.
- [6] M. Arioli, J. Maryska, M. Rozložnik, and M. Tuma. *Dual variable methods for mixed-hybrid finite element approximation of the potential fluid flow problem in porous media*. Rutherford Appleton Laboratory, 2001.
- [7] M. Arioli, V. Pták, and Z. Strakoš. Krylov sequences of maximal length and convergence of GMRES. *BIT*, 38(4):636–643, 1998.
- [8] S. F. Ashby, T. A. Manteuffel, and P. E. Saylor. Adaptive polynomial preconditioning for Hermitian indefinite linear systems. *BIT*, 29(4):583–609, 1989.
- [9] C. Ashcraft. Compressed graphs and the minimum degree algorithm. *SIAM J. Sci. Comput.*, 16(6):1404–1411, 1995.
- [10] O. Axelsson. A generalized SSOR method. *BIT*, 12(4):443–467, 1972.
- [11] O. Axelsson. Preconditioning of indefinite problems by regularization. *SIAM J. Numer. Anal.*, 16(1):58–69, 1979.
- [12] O. Axelsson. A survey of preconditioned iterative methods for linear systems of algebraic equations. *BIT*, 25(1):165–187, 1985.
- [13] O. Axelsson. A general incomplete block-matrix factorization method. *Linear Algebra Appl.*, 74(C):179–190, 1986.
- [14] O. Axelsson. *Iterative solution methods*. Cambridge university press, 1996.
- [15] O. Axelsson, S. Brinkkemper, and V. P. Il’in. On some versions of incomplete block-matrix factorization iterative methods. *Linear Algebra Appl.*, 58(C):3–15, 1984.

- [16] O. Axelsson and L. Kolotilina. Diagonally compensated reduction and related preconditioning methods. *Numer. Linear Algebra Appl.*, 1(2):155–177, 1994.
- [17] O. Axelsson and M. Neytcheva. Preconditioning methods for linear systems arising in constrained optimization problems. *Numerical Linear Algebra with Applications*, 10(1-2):3–31.
- [18] O. Axelsson and M. Neytcheva. Preconditioning methods for linear systems arising in constrained optimization problems. *Numer. Linear Algebra Appl.*, 10(1-2):3–31, 2003.
- [19] O. Axelsson and M. Neytcheva. Eigenvalue estimates for preconditioned saddle point matrices. *Numer. Linear Algebra Appl.*, 13(4):339–360, 2006.
- [20] O. Axelsson and P. S. Vassilevski. Algebraic multilevel preconditioning methods. I. *Numer. Math.*, 56(2-3):157–177, 1989.
- [21] O. Axelsson and P. S. Vassilevski. Algebraic multilevel preconditioning methods II. *SIAM J. Numer. Anal.*, 27(6):1569–1590, 1990.
- [22] R. N. Banerjee and M. W. Benson. An approximate inverse based multigrid approach to the biharmonic problem. *Int. J. Comput. Math.*, 40(3-4):201–210, 1991.
- [23] R. E. Bank and R. K. Smith. Incomplete factorization multigraph algorithm. *SIAM J. Sci. Comput.*, 20(4):1349–1364, 1999.
- [24] R. E. Bank and C. Wagner. Multilevel ILU decomposition. *Numer. Math.*, 82(4):543–576, 1999.
- [25] S. T. Barnard, L. M. Bernardo, and H. D. Simon. MPI implementation of the SPAI preconditioner on the T3E. *Int. J. High Perform. Comput. Appl.*, 13(2):107–123, 1999.
- [26] S. T. Barnard, R. L. Clay, and M. K. Chancellor. A portable MPI implementation of the SPAI preconditioner in ISIS++. *NASA technical report*, 1997.
- [27] S. T. Barnard and M. J. Grote. A block version of the SPAI preconditioner. In *PPSC*, 1999.
- [28] R. Barrett, M. Berry, T. Chan, J. Demmel, J. Donato, J. Dongarra, V. Eijkhout, R. Pozo, C. Romine, and H. van der Vorst. *Templates for the Solution of Linear Systems: Building Blocks for Iterative Methods*. SIAM publications, Philadelphia, PA, 1994.
- [29] M. Bebendorf. *Hierarchical matrices*. Springer-Verlag, Berlin Heidelberg, 2008.

- [30] B. Beckermann, S. A. Goreinov, and E. E. Tyrtyshnikov. Some remarks on the Elman estimate for GMRES. *SIAM J. Matrix Anal. Appl.*, 27(3):772–778, 2005.
- [31] M. Benson. Frequency domain behavior of a set of parallel multigrid smoothing operators. *Int. J. Comput. Math.*, 36(1-2):77–88, 1990.
- [32] M. W. Benson. An approximate inverse based multigrid approach to thin domain problems. *Util. Math.*, 45:39, 1994.
- [33] M. Benzi. Preconditioning techniques for large linear systems: A survey. *J. Comput. Phys.*, 182(2):418–477, 2002.
- [34] M. Benzi, J. K. Cullum, and M. Tũma. Robust approximate inverse preconditioning for the conjugate gradient method. *SIAM J. Sci. Comput.*, 22(4):1318–1332, 2001.
- [35] M. Benzi, G. H. Golub, and J. Liesen. Numerical solution of saddle point problems. *Acta Numer.*, 14:1–137, 2005.
- [36] M. Benzi, J. C. Haws, and M. Tũma. Preconditioning highly indefinite and nonsymmetric matrices. *SIAM J. Sci. Comput.*, 22(4):1333–1353, 2001.
- [37] M. Benzi, W. Joubert, and A. N. D. Gabriel Mateescu. Numerical experiments with parallel orderings for ILU preconditioners. *Electron. Trans. Numer. Anal.*, 8:88–114, 1999.
- [38] M. Benzi, R. Kouhia, and M. Tũma. An assessment of some preconditioning techniques in shell problems. *Commun. Numer. Methods Eng.*, 14(10):897–906, 1998.
- [39] M. Benzi, R. Kouhia, and M. Tũma. Stabilized and block approximate inverse preconditioners for problems in solid and structural mechanics. *Comput. Methods Appl. Mech. Eng.*, 190(49-50):6533–6554, 2001.
- [40] M. Benzi, J. Marín, and M. Tũma. A two-level parallel preconditioner based on sparse approximate inverses. *Iterative Methods in Scientific Computation IV*, 5:167–178, 1999.
- [41] M. Benzi, C. D. Meyer, and M. Tũma. A sparse approximate inverse preconditioner for the conjugate gradient method. *SIAM J. Sci. Comput.*, 17(5):1135–1149, 1996.
- [42] M. Benzi, D. B. Szyld, and A. Van Duin. Orderings for incomplete factorization preconditioning of nonsymmetric problems. *SIAM J. Sci. Comput.*, 20(5):1652–1670, 1999.

- [43] M. Benzi and M. Tũma. A sparse approximate inverse preconditioner for nonsymmetric linear systems. *SIAM J. Sci. Comput.*, 19(3):968–994, 1998.
- [44] M. Benzi and M. Tũma. Comparative study of sparse approximate inverse preconditioners. *Appl. Numer. Math.*, 30(2):305–340, 1999.
- [45] M. Benzi and M. Tũma. Orderings for factorized sparse approximate inverse preconditioners. *SIAM J. Sci. Comput.*, 21(5):1851–1868, 2000.
- [46] M. Benzi and M. Tũma. A parallel solver for large-scale Markov chains. *Appl. Numer. Math.*, 41(1):135–153, 2002.
- [47] M. Benzi and M. Tũma. A robust incomplete factorization preconditioner for positive definite matrices. *Numer. Linear Algebra Appl.*, 2004.
- [48] L. Bergamaschi, J. Gondzio, and G. Zilli. Preconditioning indefinite systems in interior point methods for optimization. *Comput. Optim. Appl.*, 28:149–171, 2004.
- [49] L. Bergamaschi, G. Pini, and F. Sartoretto. Approximate inverse preconditioning in the parallel solution of sparse eigenproblems. *Numer. Linear Algebra. Appl.*, 7(3):99–116, 2000.
- [50] L. Bergamaschi, G. Pini, and F. Sartoretto. Parallel preconditioning of a sparse eigensolver. *Parallel Comput.*, 27(7):963–976, 2001.
- [51] A. Berman and R. J. Plemmons. *Nonnegative matrices in the mathematical sciences*. SIAM publications, 1994.
- [52] D. Bertaccini and F. Durastante. *Iterative methods and preconditioning for large and sparse linear systems with applications*. CRC Press, 2018.
- [53] P. Birken, J. Bull, and A. Jameson. Preconditioned smoothers for the full approximation scheme for the rans equations. *J. Sci. Comput.*, 78(2):995–1022, 2019.
- [54] M. Bollhöfer. A robust ILU with pivoting based on monitoring the growth of the inverse factors. *Linear Algebra Appl.*, 338(1-3):201–218, 2001.
- [55] M. Bollhöfer. A robust and efficient ILU that incorporates the growth of the inverse triangular factors. *SIAM J. Sci. Comput.*, 25(1):86–103, 2003.
- [56] M. Bollhöfer and V. Mehrmann. Algebraic multilevel methods and sparse approximate inverses. *SIAM J. Matrix Anal. Appl.*, 24(1):191–218, 2003.
- [57] M. Bollhöfer and Y. Saad. A factored approximate inverse preconditioner with pivoting. *SIAM J. Matrix Anal. Appl.*, 23(3):692–705, 2002.

- [58] M. Bollhöfer and Y. Saad. On the relations between ILUs and factored approximate inverses. *SIAM J. Matrix Anal. Appl.*, 24(1):219–237, 2003.
- [59] Y. Y. Botros and J. L. Volakis. Preconditioned generalized minimal residual iterative scheme for perfectly matched layer terminated applications. *IEEE Microwave and Guided Wave Letters*, 9(2):45–47, 1999.
- [60] E. F. F. Botta and F. W. Wubs. Matrix renumbering ILU: An effective algebraic multilevel ILU preconditioner for sparse matrices. *SIAM J. Matrix Anal. Appl.*, 20(4):1007–1026, 1999.
- [61] J. H. Bramble. *Multigrid methods*. Chapman and Hall/CRC, 2018.
- [62] C. Brand. An incomplete-factorization preconditioning using repeated red-black ordering. *Numer. Math.*, 61(1):433–454, 1992.
- [63] A. Brandt, S. F. McCormick, and J. W. Ruge. Algebraic multigrid (AMG) for sparse matrix equations. *Sparsity and Its Applications*, pages 257–284, 1984.
- [64] R. Bridson and W.-P. Tang. Ordering, anisotropy, and factored sparse approximate inverses. *SIAM J. Sci. Comput.*, 21(3):867–882, 1999.
- [65] R. Bridson and W.-P. Tang. Refining an approximate inverse. *J. Comput. Appl. Math.*, 22:1527, 2000.
- [66] R. Bridson and W.-P. Tang. A structural diagnosis of some IC orderings. *SIAM J. Sci. Comput.*, 22(5):1527–1532, 2001.
- [67] W. L. Briggs, V. E. Henson, and S. F. McCormick. *A Multigrid Tutorial*. SIAM publications, Philadelphia, PA, second edition, 2000.
- [68] O. Bröker, M. Grote, C. Mayer, and A. Reusken. Robust parallel smoothing for multigrid via sparse approximate inverses. *SIAM J. Sci. Comput.*, 23(4):1396–1417, 2002.
- [69] O. Bröker and M. J. Grote. Sparse approximate inverse smoothers for geometric and algebraic multigrid. *Appl. Numer. Math.*, 41(1):61–80, 2002.
- [70] P. N. Brown. A linear algebraic development of diffusion synthetic acceleration for three-dimensional transport equations. *SIAM J. Numer. Anal.*, 32(1):179–214, 1995.
- [71] A. M. Bruaset. *A survey of preconditioned iterative methods*, volume 328. CRC Press, 1995.
- [72] X. Cai. Overlapping domain decomposition methods. In *Advanced Topics in Computational Partial Differential Equations*, pages 57–95. Springer-Verlag, Berlin Heidelberg, 2003.

- [73] S. L. Campbell, I. C. F. Ipsen, C. T. Kelley, and C. D. Meyer. GMRES and the minimal polynomial. *BIT*, 36(4):664–675, 1996.
- [74] B. Carpentieri, I. S. Duff, and L. Giraud. Sparse pattern selection strategies for robust Frobenius-norm minimization preconditioners in electromagnetism. *Numer. Linear Algebra. Appl.*, 7(7-8):667–685, 2000.
- [75] B. Carpentieri, I. S. Duff, L. Giraud, and M. Magolu monga Made. Sparse symmetric preconditioners for dense linear systems in electromagnetism. *Numer. Linear Algebra Appl.*, 11(8-9):753–771, 2004.
- [76] B. Carpentieri, I. S. Duff, L. Giraud, and G. Sylvand. Combining fast multipole techniques and an approximate inverse preconditioner for large parallel electromagnetics calculations. *Technical Report*, 2002.
- [77] T. F. Chan, W. P. Tang, and W. L. Wan. Wavelet sparse approximate inverse preconditioners. *BIT*, 37(3):644–660, 1997.
- [78] T. F. Chan and H. A. van der Vorst. Approximate and incomplete factorizations. *Parallel Numerical Algorithms*, 4:167–202, 1997.
- [79] W. Chang, F. Giraldo, and B. Perot. Analysis of an exact fractional step method. *J. Comput. Phys.*, 180(1):183–199, 2002.
- [80] A. Chapman, Y. Saad, and L. Wigton. High-order ILU preconditioners for CFD problems. *Int. J. Numer. Methods Fluids*, 33(6):767–788, 2000.
- [81] K. Chen. On a class of preconditioning methods for dense linear systems from boundary elements. *SIAM J. Sci. Comput.*, 20(2):684–698, 1998.
- [82] K. Chen. Discrete wavelet transforms accelerated sparse preconditioners for dense boundary element systems. *Electron. Trans. Numer. Anal.*, 8:138–153, 1999.
- [83] K. Chen. An analysis of sparse approximate inverse preconditioners for boundary integral equations. *SIAM J. Matrix Anal. Appl.*, 22(4):1058–1078, 2001.
- [84] K. Chen. *Matrix preconditioning techniques and applications*, volume 19. Cambridge University Press, 2005.
- [85] E. Chow. Priori sparsity patterns for parallel sparse approximate inverse preconditioners. *SIAM J. Sci. Comput.*, 21(5):1804–1822, 2000.
- [86] E. Chow. Parallel implementation and practical use of sparse approximate inverse preconditioners with a priori sparsity patterns. *Int. J. High Perform. Comput. Appl.*, 15(1):56–74, 2001.

- [87] E. Chow and Y. Saad. Approximate inverse techniques for block-partitioned matrices. *SIAM J. Sci. Comput.*, 18(6):1657–1675, 1997.
- [88] E. Chow and Y. Saad. Experimental study of ILU preconditioners for indefinite matrices. *J. Comput. Appl. Math.*, 86(2):387–414, 1997.
- [89] E. Chow and Y. Saad. ILUS: An incomplete LU preconditioner in sparse skyline format. *Int. J. Numer. Methods Fluids*, 25(7):739–748, 1997.
- [90] E. Chow and Y. Saad. Approximate inverse preconditioners via sparse-sparse iterations. *SIAM J. Sci. Comput.*, 19(3):995–1023, 1998.
- [91] A. J. Cleary, R. D. Falgout, V. E. Henson, J. E. Jones, T. A. Manteuffel, S. F. McCormick, G. N. Miranda, and J. W. Ruge. Robustness and scalability of algebraic multigrid. *SIAM J. Sci. Comput.*, 21(5):1886–1908, 2000.
- [92] S. S. Clift and W.-P. Tang. Weighted graph based ordering techniques for preconditioned conjugate gradient methods. *BIT*, 35(1):30–47, 1995.
- [93] P. Concus, G. H. Golub, and G. Meurant. Block preconditioning for the conjugate gradient method. *SIAM J. Sci. Statist. Comput.*, 6(1):220–252, 1985.
- [94] P. Concus, G. H. Golub, and D. P. O’Leary. A generalized conjugate gradient method for the numerical solution of elliptic partial differential equations. *Sparse Matrix Computations*, pages 309–332, 1976.
- [95] J. D. F. Cosgrove. Approximate inverse preconditionings for sparse linear systems. *Int. J. Comput. Math.*, 44(1-4):91–110, 1992.
- [96] E. Cuthill. Several strategies for reducing the bandwidth of matrices. *Sparse Matrices and Their Applications*, pages 157–166, 1972.
- [97] W. Dahmen and L. Elsner. Algebraic multigrid methods and the Schur complement. *Notes Numer. Fluid Mech.*, 23:58–68, 1989.
- [98] E. F. D’Azevedo, P. A. Forsyth, and W. Tang. Two variants of minimum discarded fill ordering. *Proc. IMACS Int. Symp. on Iterative Methods in Linear Algebra*, pages 603–612, 1992.
- [99] E. F. D’Azevedo, P. A. Forsyth, and W.-P. Tang. Ordering methods for preconditioned conjugate gradient methods applied to unstructured grid problems. *SIAM J. Matrix Anal. Appl.*, 13(3):944–961, 1992.
- [100] E. de Doncker and A. Gupta. Coarse grain preconditioned conjugate gradient solver for large sparse systems. In *PPSC*, pages 472–477, 1995.

- [101] E. de Sturler and J. Liesen. Block-diagonal and constraint preconditioners for nonsymmetric indefinite linear systems. Part I: Theory. *SIAM J. Sci. Comput.*, 26(5):1598–1619, 2005.
- [102] S. Demko, W. F. Moss, and P. W. Smith. Decay rates for inverses of band matrices. *Math. Comput.*, 43(168):491–499, 1984.
- [103] J. Demmel. *Applied Numerical Linear Algebra*. SIAM publications, Philadelphia, PA, 1997.
- [104] J. Dendy. Black box multigrid. *J. Comput. Phys.*, 48(3):366–386, 1982.
- [105] J. C. Diaz and K. Komara. Incomplete multilevel Cholesky factorizations. *SIAM J. Matrix Anal. Appl.*, 22(3):895–911, 2000.
- [106] S. Doi. On parallelism and convergence of incomplete LU factorizations. *Appl. Numer. Math.*, 7(5):417–436, 1991.
- [107] S. Doi and T. Washio. Ordering strategies and related techniques to overcome the trade-off between parallelism and convergence in incomplete factorizations. *Parallel Comput.*, 25(13):1995–2014, 1999.
- [108] V. Dolean, P. Jolivet, and F. Nataf. *An introduction to domain decomposition methods: algorithms, theory, and parallel implementation*. SIAM publications, Philadelphia, PA, 2015.
- [109] H. S. Dollar, N. I. Gould, W. H. Schilders, and A. J. Wathen. On iterative methods and implicit-factorization preconditioners for regularized saddle-point systems. Technical report, Rutherford Appleton Laboratory, 2005.
- [110] J. Drkošová, A. Greenbaum, M. Rozložník, and Z. Strakoš. Numerical stability of GMRES. *BIT*, 35(3):309–330, 1995.
- [111] I. S. Duff, A. M. Erisman, C. W. Gear, and J. K. Reid. Sparsity structure and Gaussian elimination. *SIGNAL Newsletter*, 23(2):2–8, 1988.
- [112] I. S. Duff and J. Koster. The design and use of algorithms for permuting large entries to the diagonal of sparse matrices. *SIAM J. Matrix Anal. Appl.*, 20(4):889–901, 1999.
- [113] I. S. Duff and J. Koster. On algorithms for permuting large entries to the diagonal of a sparse matrix. *SIAM J. Matrix Anal. Appl.*, 22(4):973–996, 2001.
- [114] I. S. Duff and G. A. Meurant. The effect of ordering on preconditioned conjugate gradients. *BIT*, 29(4):635–657, 1989.

- [115] L. C. Dutto. The effect of ordering on preconditioned GMRES algorithm, for solving the compressible Navier–Stokes equations. *Int. J. Numer. Methods Eng.*, 36(3):457–497, 1993.
- [116] M. Eiermann and O. G. Ernst. Geometric aspects of the theory of Krylov subspace methods. *Acta Numer.*, 10:251–312, 2001.
- [117] V. Eijkhout. Analysis of parallel incomplete point factorizations. *Linear Algebra Appl.*, 154-156(C):723–740, 1991.
- [118] V. Eijkhout. Beware of unperturbed modified incomplete factorizations. *Iterative Methods in Linear Algebra*, 583:583–591, 1992.
- [119] S. C. Eisenstat. Efficient implementation of a class of preconditioned conjugate gradient methods. *SIAM J. Sci. Stat. Comput.*, 2(1):1–4, 1981.
- [120] S. C. Eisenstat, H. C. Elman, and M. H. Schultz. Variational iterative methods for nonsymmetric systems of linear equations. *SIAM J. Numer. Anal.*, 20(2):345–357, 1983.
- [121] H. C. Elman. A stability analysis of incomplete LU factorizations. *Math. Comput.*, 47(175):191–217, 1986.
- [122] B. Engquist and L. Ying. Sweeping preconditioner for the Helmholtz equation: Hierarchical matrix representation. *Comm. Pure Appl. Math.*, 64(5):697–735, 2011.
- [123] O. G. Ernst and M. J. Gander. Why it is difficult to solve Helmholtz problems with classical iterative methods. In *Numerical analysis of multiscale problems*, pages 325–363. Springer-Verlag, Berlin Heidelberg, 2012.
- [124] C. Farhat, J. Mandel, and F. X. Roux. Optimal convergence properties of the FETI domain decomposition method. *Comput. Methods Appl. Mech. Eng.*, 115(3-4):365–385, 1994.
- [125] M. R. Field. An efficient parallel preconditioner for the conjugate gradient algorithm. *Hitachi Dublin Laboratory Technical Report HDL-TR-97-175, Dublin, Ireland*, 1997.
- [126] M. R. Field. Improving the performance of factorised sparse approximate inverse preconditioner. *Technical Report HDL-TR-98-199*, 1998.
- [127] B. Fischer. *Polynomial based iteration methods for symmetric linear systems*. Springer, 1996.
- [128] R. Fletcher. Conjugate gradient methods for indefinite systems. *Lecture Notes in Math.*, 506:73–89, 1976.

- [129] A. Forsgren, P. E. Gill, and J. D. Griffin. Iterative solution of augmented systems arising in interior methods. *SIAM J. Optim.*, 18(2):666–690, 2007.
- [130] A. Forsgren, P. E. Gill, and M. H. Wright. Interior methods for nonlinear optimization. *SIAM Rev.*, 44(4):525–597 (2003), 2002.
- [131] R. W. Freund. A transpose-free quasi-minimal residual algorithm for non-hermitian linear systems. *SIAM J. Sci. Comput.*, 14(2):470–482, 1993.
- [132] R. W. Freund and N. M. Nachtigal. QMR: a quasi-minimal residual method for non-Hermitian linear systems. *Numer. Math.*, 60(1):315–339, 1991.
- [133] R. W. Freund, N. M. Nachtigal, and G. H. Golub. Iterative solution of linear systems. *Acta Numer.*, 1:57–100, 1992.
- [134] M. J. Gander, I. G. Graham, and E. A. Spence. Applying GMRES to the Helmholtz equation with shifted Laplacian preconditioning: What is the largest shift for which wavenumber-independent convergence is guaranteed? *Numer. Math.*, 131(3):567–614, 2015.
- [135] A. George and J. W. Liu. *Computer solution of large sparse positive definite*. Prentice Hall Professional Technical Reference, 1981.
- [136] A. George and J. W. H. Liu. An implementation of a pseudoperipheral node finder. *ACM Trans. Math. Softw.*, 5(3):284–295, 1979.
- [137] A. George and J. W. H. Liu. Evolution of the minimum degree ordering algorithm. *SIAM Rev.*, 31(1):1–19, 1989.
- [138] J. R. Gilbert. Predicting structure in sparse matrix computations. *SIAM J. Matrix Anal. Appl.*, 15(1):62–79, 1994.
- [139] G. H. Golub and D. P. O’Leary. Some history of the conjugate gradient and Lanczos algorithms: 1948-1976. *SIAM Rev.*, 31(1):50–102, 1989.
- [140] G. H. Golub and C. F. Van Loan. *Matrix Computations*. Johns Hopkins University Press, Baltimore, MD, fourth edition, 2013.
- [141] G. H. Golub and Q. Ye. Inexact preconditioned conjugate gradient method with inner-outer iteration. *SIAM J. Sci. Comput.*, 21(4):1305–1320, 1999.
- [142] N. Gould, D. Orban, and T. Rees. Projected Krylov methods for saddle-point systems. *SIAM J. Matrix Anal. Appl.*, 35(4):1329–1343, 2014.
- [143] N. I. M. Gould and J. A. Scott. Sparse approximate-inverse preconditioners using norm-minimization techniques. *SIAM J. Sci. Comput.*, 19(2):605–625, 1998.

- [144] C. Gräser and R. Kornhuber. Nonsmooth Newton methods for set-valued saddle point problems. *SIAM J. Numer. Anal.*, 47(2):1251–1273, 2009.
- [145] A. Greenbaum. Analysis of a multigrid method as an iterative technique for solving linear systems. *SIAM J. Numer. Anal.*, 21(3):473–485, 1984.
- [146] A. Greenbaum. *Iterative Methods for Solving Linear Systems*. SIAM publications, Philadelphia, PA, 1997.
- [147] A. Greenbaum, V. Pták, and Z. Strakoš. Any nonincreasing convergence curve is possible for GMRES. *SIAM J. Matrix Anal. Appl.*, 17(3):465–469, 1996.
- [148] A. Greenbaum and Z. Strakoš. Predicting the behavior of finite precision Lanczos and conjugate gradient computations. *SIAM J. Matrix Anal. Appl.*, 13(1):121–137, 1992.
- [149] A. Greenbaum and L. N. Trefethen. GMRES/CR and Arnoldi/Lanczos as matrix approximation problems. *SIAM J. Sci. Comput.*, 15(2):359–368, 1994.
- [150] G. Haase. Parallel incomplete Cholesky preconditioners based on the non-overlapping data distribution. *Parallel Comput.*, 24(11):1685–1703, 1998.
- [151] W. Hackbusch. *Multi-grid methods and applications*, volume 4. Springer-Verlag, Berlin Heidelberg, 1985.
- [152] W. Hackbusch. *Iterative solution of large sparse systems of equations*, volume 95. Springer-Verlag, New York, 1994.
- [153] W. Hackbusch. *Hierarchical matrices: Algorithms and analysis*. Springer-Verlag, Berlin Heidelberg, 2015.
- [154] L. A. Hageman and D. M. Young. *Applied iterative methods*. Courier Corporation, 2012.
- [155] M. R. Hestenes and E. Stiefel. Methods of conjugate gradients for solving linear systems. *Journal of research of the National Bureau of Standards*, 49:409–436, 1952.
- [156] N. J. Higham. The matrix computation toolbox. Version 1.2. Available from: <http://www.ma.man.ac.uk/~higham/mctoolbox/>, 2002.
- [157] N. J. Higham. Functions of matrices. In L. Hogben, editor, *Handbook of linear algebra*. CRC Press, 2006.
- [158] I. Hladík, M. B. Reed, and G. Swoboda. Robust preconditioners for linear elasticity FEM analyses. *Int. J. Numer. Methods Eng.*, 40(11):2109–2127, 1997.

- [159] R. A. Horn and C. R. Johnson. *Matrix Analysis*. Cambridge University Press, Cambridge, UK, second edition, 2012.
- [160] T. Huckle. Approximate sparsity patterns for the inverse of a matrix and preconditioning. *Appl. Numer. Math.*, 30(2):291–303, 1999.
- [161] T. Huckle. Factorized sparse approximate inverses for preconditioning and smoothing. *Selčuk J. Appl. Math.*, 1:63, 2000.
- [162] T. Huckle. Factorized sparse approximate inverses for preconditioning. *The Journal of Supercomputing*, 25(2):109–117, 2003.
- [163] D. Hysom and A. Pothen. A scalable parallel algorithm for incomplete factor preconditioning. *SIAM J. Sci. Comput.*, 22(6):2194–2215, 2001.
- [164] D. A. Hysom. *New sequential and scalable parallel algorithms for incomplete factor preconditioning*. PhD thesis, Old Dominion University, 2001.
- [165] V. P. Il'in. *Iterative Incomplete Factorization Methods*, volume 4. World Scientific, 1992.
- [166] V. John. Multigrid methods. Lecture notes from Weierstrass Institute for Applied Analysis and Stochastics. Available from: <https://www.wias-berlin.de/people/john/LEHRE/MULTIGRID/multigrid.pdf>, 2013.
- [167] O. G. Johnson, C. A. Micchelli, and G. Paul. Polynomial preconditioners for conjugate gradient calculations. *SIAM J. Numer. Anal.*, 20(2):362–376, 1983.
- [168] S. G. Johnson. Notes on perfectly matched layers (PMLs). *Lecture notes, Massachusetts Institute of Technology, Massachusetts*, 29, 2008.
- [169] M. T. Jones and P. E. Plassmann. Scalable iterative solution of sparse linear systems. *Parallel Comput.*, 20(5):753–773, 1994.
- [170] M. T. Jones and P. E. Plassmann. An improved incomplete Cholesky factorization. *ACM Trans. Math. Softw.*, 21(1):5–17, 1995.
- [171] I. E. Kaporin. New convergence results and preconditioning strategies for the conjugate gradient method. *Numer. Linear Algebra. Appl.*, 1(2):179–210, 1994.
- [172] I. E. Kaporin. High quality preconditioning of a general symmetric positive definite matrix based on its UTU + UTR + RTU-decomposition. *Numer. Linear Algebra. Appl.*, 5(6):483–509, 1998.
- [173] I. E. Kaporin and I. N. Konshin. A parallel block overlap preconditioning with inexact submatrix inversion for linear elasticity problems. *Numer. Linear Algebra. Appl.*, 9(2):141–162, 2002.

- [174] G. Karypis and V. Kumar. Parallel threshold-based ILU factorization. In *SC'97: Proceedings of the 1997 ACM/IEEE Conference on Supercomputing*, pages 28–28. IEEE, 1997.
- [175] G. Karypis and V. Kumar. A fast and high quality multilevel scheme for partitioning irregular graphs. *SIAM J. Sci. Comput.*, 20(1):359–392, 1998.
- [176] C. Keller, N. I. M. Gould, and A. J. Wathen. Constraint preconditioning for indefinite linear systems. *SIAM J. Matrix Anal. Appl.*, 21(4):1300–1317, 2000.
- [177] D. S. Kershaw. The incomplete Cholesky-conjugate gradient method for the iterative solution of systems of linear equations. *J. Comput. Phys.*, 26(1):43–65, 1978.
- [178] S. A. Kharchenko, L. Y. Kolotilina, A. A. Nikishin, and A. Y. Yeremin. A robust AINV-type method for constructing sparse approximate inverse preconditioners in factored form. *Numer. Linear Algebra. Appl.*, 8(3):165–179, 2001.
- [179] A. V. Knyazev. Preconditioned eigensolvers - an oxymoron? *Electron. Trans. Numer. Anal.*, 7:104–123, 1998.
- [180] L. Y. Kolotilina, A. A. Nikishin, and A. Y. Yeremin. Factorized sparse approximate inverse preconditionings IV: Simple approaches to rising efficiency. *Numer. Linear Algebra. Appl.*, 6(7):515–531, 1999.
- [181] L. Y. Kolotilina and A. Y. Yeremin. On a family of two-level preconditionings of the incomplete block factorization type. *Russ. J. Numer. Anal. Math. Modell.*, 1(4):293–320, 1986.
- [182] L. Y. Kolotilina and A. Y. Yeremin. Factorized sparse approximate inverse preconditionings I: Theory. *SIAM J. Matrix Anal. Appl.*, 14(1):45–58, 1993.
- [183] L. Y. Kolotilina and A. Y. Yeremin. Factorized sparse approximate inverse preconditioning II: Solution of 3D FE systems on massively parallel computers. *International Journal of High Speed Computing*, 7:191–215, 1995.
- [184] A. Krechel and K. Stüben. Parallel algebraic multigrid based on subdomain blocking. *Parallel Comput.*, 27(8):1009–1031, 2001.
- [185] C. Lanczos. Solution of systems of linear equations by minimized iterations. *J. Res. Nat. Bur. Standards*, 49(1):33–53, 1952.
- [186] Z. Li, Y. Saad, and M. Sosonkina. PARMS: A parallel version of the algebraic recursive multilevel solver. *Technical Report*, 2001.

- [187] J. Liesen and P. Tichý. The field of values bound on ideal GMRES. Technical report, TU Berlin, 2013. arXiv:1211.5969v2.
- [188] C.-J. Lin and J. J. Moré. Incomplete Cholesky factorizations with limited memory. *SIAM J. Sci. Comput.*, 21(1):24–45, 1999.
- [189] C.-J. Lin and R. Saigal. An incomplete Cholesky factorization for dense symmetric positive definite matrices. *BIT*, 40(3):536–558, 2000.
- [190] Q. Liu, R. B. Morgan, and W. Wilcox. Polynomial preconditioned GMRES and GMRES-DR. *SIAM J. Sci. Comput.*, 37(5):S407–S428, 2015.
- [191] J. A. Loe and R. B. Morgan. New polynomial preconditioned GMRES. *arXiv preprint arXiv:1911.07065*, 2019.
- [192] J.-C. Luo. Algorithms for reducing the bandwidth and profile of a sparse matrix. *Computers & structures*, 44(3):535–548, 1992.
- [193] M. Magolu monga Made. Incomplete factorization-based preconditionings for solving the Helmholtz equation. *Int. J. Numer. Methods Eng.*, 50(5):1077–1101, 2001.
- [194] M. Magolu monga Made, R. Beauwens, and G. Warzée. Preconditioning of discrete Helmholtz operators perturbed by a diagonal complex matrix. *Commun. Numer. Methods Eng.*, 16(11):801–817, 2000.
- [195] M. Magolu monga Made and B. Polman. Experimental comparison of three-dimensional point and line modified incomplete factorizations. *Numer. Algorithms*, 23(1):51–70, 2000.
- [196] M. Magolu monga Made and H. A. van der Vorst. Parallel incomplete factorizations with pseudo-overlapped subdomains. *Parallel Comput.*, 27(8):989–1008, 2001.
- [197] J. A. Meijerink and H. A. van der Vorst. An iterative solution method for linear systems of which the coefficient matrix is a symmetric M-matrix. *Math. Comput.*, 31(137):148–162, 1977.
- [198] G. Meurant. *Computer solution of large linear systems*. Elsevier, 1999.
- [199] G. Meurant. Numerical experiments with algebraic multilevel preconditioners. *Electron. Trans. Numer. Anal.*, 12:1–65, 2001.
- [200] G. Meurant. A multilevel AINV preconditioner. *Numer. Algorithms*, 29(1-3):107–129, 2002.
- [201] O. Y. Milyukova. Parallel approximate factorization method for solving discrete elliptic equations. *Parallel Comput.*, 27(10):1365–1379, 2001.

- [202] A. Moiola and E. A. Spence. Is the Helmholtz equation really sign-indefinite? *SIAM Rev.*, 56(2):274–312, 2014.
- [203] R. B. Morgan. Preconditioning eigenvalues and some comparison of solvers. *J. Comput. Appl. Math.*, 123(1-2):101–115, 2000.
- [204] R. B. Morgan and Z. Yang. Two-grid and multiple-grid Arnoldi for eigenvalues. *SIAM J. Sci. Comput.*, 40(5):A3470–A3494, 2018.
- [205] V. A. Mousseau, D. A. Knoll, and W. J. Rider. Physics-based preconditioning and the Newton-Krylov method for non-equilibrium radiation diffusion. *J. Comput. Phys.*, 160(2):743–765, 2000.
- [206] M. F. Murphy, G. H. Golub, and A. J. Wathen. Note on preconditioning for indefinite linear systems. *SIAM J. Sci. Comput.*, 21(6):1969–1972, 2000.
- [207] M. F. Murphy, G. H. Golub, and A. J. Wathen. A note on preconditioning for indefinite linear systems. *SIAM J. Sci. Comput.*, 21(6):1969–1972, 2000.
- [208] E. Ng, B. Peyton, and P. Raghavan. A blocked incomplete Cholesky preconditioner for hierarchical-memory computers. *Iterative Methods in Scientific Computation IV*, 5:211–221, 1999.
- [209] J. Nocedal and S. J. Wright. *Numerical optimization*. Springer Series in Operations Research and Financial Engineering. Springer, New York, second edition, 2006.
- [210] Y. Notay. Using approximate inverses in algebraic multilevel methods. *Numer. Math.*, 80(3):397–417, 1998.
- [211] Y. Notay. Multilevel block incomplete factorization preconditioning. *Appl. Numer. Math.*, 31(2):209–225, 1999.
- [212] Y. Notay. Flexible conjugate gradients. *SIAM J. Sci. Comput.*, 22(4):1444–1460, 2001.
- [213] J. O’Neil and D. B. Szyld. A block ordering method for sparse matrices. *SIAM J. Sci. Stat. Comput.*, 11(5):811–823, 1990.
- [214] A. Padiy, O. Axelsson, and B. Polman. Generalized augmented matrix preconditioning approach and its application to iterative solution of ill-conditioned algebraic systems. *SIAM J. Matrix Anal. Appl.*, 22(3):793–818, 2000.
- [215] C. C. Paige and M. A. Saunders. Solution of sparse indefinite systems of linear equations. *SIAM J. Numer. Anal.*, 12(4):617–629, 1975.
- [216] C. H. Papadimitriou and K. Steiglitz. *Combinatorial optimization: algorithms and complexity*. Dover Publications, Mineola, NY, 1998.

- [217] J. W. Pearson and A. J. Wathen. A new approximation of the schur complement in preconditioners for pde-constrained optimization. *Numer. Linear Algebra Appl.*, 19(5):816–829, 2012.
- [218] R. J. Plemmons. M–matrix characterizations. I–nonsingular M–matrices. *Linear Algebra Appl.*, 18(2):175–188, 1977.
- [219] A. Quarteroni and A. Valli. *Domain decomposition methods for partial differential equations*. Oxford University Press, 1999.
- [220] A. Quarteroni and A. Valli. *Numerical approximation of partial differential equations*. Springer-Verlag, Berlin Heidelberg, 2008.
- [221] T. Rees, H. S. Dollar, and A. J. Wathen. Optimal solvers for PDE-constrained optimization. *SIAM J. Sci. Comput.*, 32(1):271–298, 2010.
- [222] T. Rees and M. Stoll. Block-triangular preconditioners for pde-constrained optimization. *Numerical Linear Algebra with Applications*, 17(6):977–996, 2010.
- [223] J. K. Reid. On the method of conjugate gradients for the solution of large sparse systems of linear equations. In *Pro. the Oxford conference of institute of mathematics and its applications*, pages 231–254, 1971.
- [224] A. Reusken. A multigrid method based on incomplete Gaussian elimination. *Numer. Linear Algebra. Appl.*, 3(5):369–390, 1996.
- [225] Y. Robert. Regular incomplete factorizations of real positive definite matrices. *Linear Algebra Appl.*, 48(C):105–117, 1982.
- [226] M. Rozložník and V. Simoncini. Krylov subspace methods for saddle point problems with indefinite preconditioning. *SIAM J. Matrix Anal. Appl.*, 24(2):368–391, 2002.
- [227] J. W. Ruge and K. Stüben. Algebraic multigrid. In *Multigrid methods*, pages 73–130. SIAM publications, Philadelphia, PA, 1987.
- [228] O. Runborg. Helmholtz equation and high frequency approximations. Lecture notes. Available from: <http://www.csc.kth.se/utbildning/kth/kurser/DN2255/ndiff12/Lecture5.pdf>, 2012.
- [229] Y. Saad. Preconditioning techniques for nonsymmetric and indefinite linear systems. *J. Comput. Appl. Math.*, 24(1-2):89–105, 1988.
- [230] Y. Saad. Krylov subspace methods on supercomputers. *SIAM J. Sci. Stat. Comput.*, 10(6):1200–1232, 1989.
- [231] Y. Saad. *Numerical methods for large eigenvalue problems*. Manchester University Press, Manchester, UK, 1992.

- [232] Y. Saad. A flexible inner-outer preconditioned GMRES algorithm. *SIAM J. Sci. Comput.*, 14(2):461–469, 1993.
- [233] Y. Saad. Highly parallel preconditioners for general sparse matrices. In *Recent Advances in Iterative Methods*, pages 165–199. Springer, 1994.
- [234] Y. Saad. ILUT: A dual threshold incomplete LU factorization. *Numer. Linear Algebra Appl.*, 1(4):387–402, 1994.
- [235] Y. Saad. ILUM: A multi-elimination ILU preconditioner for general sparse matrices. *SIAM J. Sci. Comput.*, 17(4):830–847, 1996.
- [236] Y. Saad. Finding exact and approximate block structures for ILU preconditioning. *SIAM J. Sci. Comput.*, 24(4):1107–1123, 2003.
- [237] Y. Saad. *Iterative methods for sparse linear systems*. SIAM publications, Philadelphia, PA, second edition, 2003.
- [238] Y. Saad and M. H. Schultz. GMRES: A generalized minimal residual algorithm for solving nonsymmetric linear systems. *Syst. Control Lett.*, 7:856–869, 1986.
- [239] Y. Saad and J. Zhang. BILUM: Block versions of multielimination and multilevel ILU preconditioner for general sparse linear systems. *SIAM J. Sci. Comput.*, 20(6):2103–2121, 1999.
- [240] Y. Saad and J. Zhang. BILUTM: A domain-based multilevel block ILUT preconditioner for general sparse matrices. *SIAM J. Matrix Anal. Appl.*, 21(1):279–299, 1999.
- [241] P. Saint-Georges, G. Warzee, R. Beauwens, and Y. Notay. High-performance PCG solvers for FEM structural analysis. *Int. J. Numer. Methods Eng.*, 39(8):1313–1340, 1996.
- [242] P. Saint-Georges, G. Warzee, Y. Notay, and R. Beauwens. Problem-dependent preconditioners for iterative solvers in FE elastostatics. *Comput. Struct.*, 73(1-5):33–43, 1999.
- [243] J. R. Shewchuk. An introduction to the conjugate gradient method without the agonizing pain. Technical report, Carnegie Mellon University, Pittsburgh, PA, 1994.
- [244] V. Simoncini. Block triangular preconditioners for symmetric saddle-point problems. *Applied Numerical Mathematics*, 49(1):63 – 80, 2004. Numerical Algorithms, Parallelism and Applications.
- [245] V. Simoncini and D. B. Szyld. Recent computational developments in Krylov subspace methods for linear systems. *Numer. Linear Algebra Appl.*, 14(1):1–59, 2007.

- [246] G. L. G. Sleijpen and F. W. Wubs. Exploiting multilevel preconditioning techniques in eigenvalue computations. *SIAM J. Sci. Comput.*, 25(4):1249–1272, 2004.
- [247] S. Sloan. An algorithm for profile and wavefront reduction of sparse matrices. *Int. J. Numer. Methods Eng.*, 23(2):239–251, 1986.
- [248] B. Smith, P. Bjorstad, and W. Gropp. *Domain decomposition: parallel multilevel methods for elliptic partial differential equations*. Cambridge university press, 2004.
- [249] Z. Strakoš and J. Liesen. *Krylov Subspace Methods: Principles and Analysis*. Oxford University Press, Oxford, UK, 2012.
- [250] K. Stüben. Algebraic multigrid (AMG): experiences and comparisons. *Appl. Math. Comput.*, 13(3-4):419–451, 1983.
- [251] K. Stüben. A review of algebraic multigrid. *J. Comput. Appl. Math.*, 128(1-2):281–309, 2001.
- [252] M. Suarjana and K. H. Law. A robust incomplete factorization based on value and space constraints. *Int. J. Numer. Methods Eng.*, 38(10):1703–1719, 1995.
- [253] D. B. Szyld and J. A. Vogel. FQMR: A flexible quasi-minimal residual method with inexact preconditioning. *SIAM J. Sci. Comput.*, 23(2):363–380, 2002.
- [254] W.-P. Tang and W. L. Wan. Sparse approximate inverse smoother for multigrid. *SIAM J. Matrix Anal. Appl.*, 21(4):1236–1252, 2000.
- [255] M. Tismenetsky. A new preconditioning technique for solving large sparse linear systems. *Linear Algebra Appl.*, 154-156(C):331–353, 1991.
- [256] D. Titley-Peloquin, J. Pestana, and A. J. Wathen. GMRES convergence bounds that depend on the right-hand-side vector. *IMA J. Numer. Anal.*, 34(2):462–479, 07 2013.
- [257] L. N. Trefethen and D. I. Bau. *Numerical linear algebra*. SIAM publications, Philadelphia, PA, 1997.
- [258] L. N. Trefethen and M. Embree. *Spectra and pseudospectra. The behavior of nonnormal matrices and operators*. Princeton University Press, Princeton, NJ, 2005.
- [259] U. Trottenberg, C. W. Oosterlee, and A. Schüller. *Multigrid*. Elsevier, 2000.

- [260] R. Underwood. An approximate factorization procedure based on the block Cholesky decomposition and its use with the conjugate gradient method. *Tech. Rep. NEDO-11386*, 1976.
- [261] H. A. van der Vorst. Large tridiagonal and block tridiagonal linear systems on vector and parallel computers. *Parallel Comput.*, 5(1-2):45–54, 1987.
- [262] H. A. van der Vorst. The convergence behaviour of preconditioned CG and CG-S. *Lecture Notes in Math.*, 1457:126–136, 1990.
- [263] H. A. van der Vorst. Bi-CGSTAB: A fast and smoothly converging variant of Bi-CG for the solution of nonsymmetric linear systems. *SIAM J. Sci. Stat. Comput.*, 13(2):631–644, 1992.
- [264] R. S. Varga, E. B. Saff, and V. Mehrmann. Incomplete factorizations of matrices and connections with H-matrices. *SIAM J. Numer. Anal.*, 17(6):787–793, 1980.
- [265] P. S. Vassilevski. Block-factorization (algebraic) formulation of multigrid and Schwarz methods. *East West J. Numer. Math.*, 6(1):65–79, 1998.
- [266] C. Vuik, R. R. P. Van Nooyen, and P. Wesseling. Parallelism in ILU-preconditioned GMRES. *Parallel Comput.*, 24(14):1927–1946, 1998.
- [267] C. Wagner. Introduction to algebraic multigrid. Lecture notes from University of Heidelberg. Available from: <http://www.sam.math.ethz.ch/~mhg/unt/AMG/Wagner-AMG.ps>, 1999.
- [268] J. S. Warsa, T. A. Wareing, and J. E. Morel. Solution of the discontinuous P1 equations in two-dimensional Cartesian geometry with two-level preconditioning. *SIAM J. Sci. Comput.*, 24(6):2093–2124, 2003.
- [269] A. J. Wathen. Preconditioning. *Acta Numer.*, 24:329–376, 2015.
- [270] J. W. Watts III. A conjugate gradient-truncated direct method for the iterative solution of the reservoir simulation pressure equation. *Society of Petroleum Engineers Journal*, 21(03):345–353, 1981.
- [271] G. Wittum. On the robustness of ILU smoothing. *SIAM J. Sci. Stat. Comput.*, 10(4):699–717, 1989.
- [272] S. J. Wright. *Primal-dual interior-point methods*. Society for Industrial and Applied Mathematics (SIAM), Philadelphia, PA, 1997.
- [273] K. Wu, Y. Saad, and A. Stathopoulos. Inexact Newton preconditioning techniques for large symmetric eigenvalue problems. *Electron. Trans. Numer. Anal.*, 7:202–214, 1998.

- [274] U. M. Yang et al. BoomerAMG: A parallel algebraic multigrid solver and preconditioner. *Appl. Numer. Math.*, 41(1):155–177, 2002.
- [275] J. Zhang. A multilevel dual reordering strategy for robust incomplete LU factorization of indefinite matrices. *SIAM J. Matrix Anal. Appl.*, 22(3):925–947, 2000.
- [276] J. Zhang. Sparse approximate inverse and multilevel block ILU preconditioning techniques for general sparse matrices. *Appl. Numer. Math.*, 35(1):67–86, 2000.
- [277] C. Zhao, B. E. Hobbs, H. B. Mühlhaus, A. Ord, and G. Lin. Efficient ILU preconditioning and inexact-Newton-GMRES to solve the 2D steady shallow water equations. *Commun. Numer. Methods Eng.*, 17(2):69–75, 2001.

Index

- LDL^T factorization, 50
- acoustic waves, 41
- additive Schwarz method, 70, 84, 197, 200, 202
- additive Schwarz preconditioner, 73, 84, 199
- algebraic multigrid, 95
 - coarse and fine grid, 101
- AMG, *see* algebraic multigrid
- Arnoldi factorization, 150
- Arrow–Hurwicz, 120, 131, 241
- Block Gaussian elimination, 66
- block preconditioner, 249
- Block preconditioners, 121
- boundary element method, vi
- CG, *see* conjugate gradients
- conjugate gradients, 3
 - minimization viewpoint, 3
 - preconditioned, 5, 14
- Cuthill–McKee, 28, 37, 38
- damping, 42
- decay
 - off-diagonal blocks, 51
 - Singular values, 51
- degree, 27
- diagonal preconditioner, 121, 130
- diagonally dominant, 32
- Dirichlet–Neumann method, 68, 81, 191
- Domain decomposition, 63
 - non-overlapping domains, 64
 - uniform discretization, 64
- edge, 24
 - incoming, 24
 - outgoing, 24
 - weight, 99
- field of values, 16
- fill-in, 23
- finite difference, 44
- first-order necessary optimality conditions, 116
- Fourier modes, 88–90, 106
- full multigrid V-cycle, 95, 106
- Gauss–Seidel, 19, 33, 154
 - convergence, 21
 - fixed-point, 20, 31
- Gaussian elimination, 18
- Generalized saddle point system, 116
- Gershgorin theory, 153, 239
- GMRES, 2, 3, 126, 133
 - convergence, 6, 15
 - flexible variant, 6, 7, 229, 242
 - min-max bound, 6, 151
 - minimization viewpoint, 2
 - transient phase, 9
- graph, 24
 - adjacency matrix, 24
 - connected, 26
 - directed, 24
 - disconnected, 26
 - distance, 26
 - of a matrix, 25, 97
 - path, 25
 - separator, 37
 - undirected, 24
- H-matrices, *see* hierarchical matrices
- Helmholtz equation, 42
 - damping, 42
 - eigenvalues, 46
 - oscillations, 42, 55
 - Sommerfeld condition, 46
 - weak formulation, 58
- hierarchical matrices, 52
- ILU, 29
 - modified, 39
- ILU(p), 30, 31

- ILU(0), 29
- incomplete LU, *see* ILU
- interpolation, 94, *see also*
 - prolongation
- iterative methods, 2
 - preconditioned, 4
- Jacobi, 19
 - convergence, 21
 - fixed-point, 20, 31
- Jacobi iteration, 32, 33, 154, 155
 - block, 70
 - damped, 88, 96, 106, 235
- Jordan block, 139
- KKT conditions, *see* first-order
 - necessary optimality conditions
- KKT-matrix, 123
- Krylov subspace, 2, 115
- Lagrangian, 116
- Laplacian
 - graph, 80
- left preconditioning, 4
- LU factorization, 22
 - existence, 23
 - Fill-path, 31
 - fill-in, 23
 - interpretation, 23
 - level of fill, 30
 - reordering, 27
- M-matrix, 17, 22, 30, 32, 95
- min-max bound, 6
- minimum degree ordering, 27
- mixed preconditioning, 4
- multigrid methods, 92
- multiplicative Schwarz method, 71, 109
- multiplicative Schwarz
 - preconditioner, 74
- Nested iteration, 93
- node, 24
- normal matrix, 139
- nullspace method, 115
- PCG, *see* conjugate gradients
- perfectly matched layers, 46
- PML, *see* perfectly matched layers
- Poisson equation, 75, 81
- profile, 28
- projection, 94, *see also* restriction
 - prolongation, 103, *see also*
 - interpolation
 - direct, 104
 - Ruge–Stüben, 105
 - weights, 104
 - pscont, 11, 141
- pseudospectra, 10, 16
 - bound, 9, 15
 - definition, 9, 150
 - equivalent definitions, 10
 - properties, 10
- QMR, 2
- quadprog, 124–126, 228, 229
- quadratic programming, 115, 124, 128, 231
- reduced Hessian method, 115
- regular splitting, 22, 30, 32, 96
- residual equation, 93, 97
- restarting, 3
- restriction, 103, *see also* projection
- reverse Cuthill–McKee, *see* Cuthill–McKee
- right preconditioning, 4
- Saddle point systems, 116
 - constraint preconditioning, 118
 - Schur complement reduction, 117
 - solvability conditions, 117
- satellite, vi, 15, 148
- Schur complement, 50, 115, 236
- shifted Laplacian, 45

- short-term-recurrence methods, 3
- smooth error, 92
 - algebraically, 100
- smoothing, 90
- Sommerfeld condition, 47
- SOR, 19
 - backward, 33
 - convergence, 21
 - fixed-point, 20, 31
 - symmetric, *see* SSOR
- splitting method, 33
- spy plot, 39, 114, 164, 165, 167, 168, 195, 235
- SSOR, 20, 33
- Steklov equation, 67, 77
 - discrete, 66
- strongly depends, 99
- strongly influences, 99
- successive over-relaxation, *see* SOR
- sweeping factorization, 48, 50
- two grids method, 44, 55
- two-grid correction scheme, 94, 109
- two-sided preconditioning, 4
- uniform discretization, 64
- Uzawa's method, 119, 129, 235, 239, 241, 242
 - block, 133
 - inexact, 132
 - optimal parameter, 236
 - reformulation, 235
- V-cycle, 95, 106
- vertex, *see* node
- W-cycle, 106
- wavenumber, 42
- Zarantonello bound, 6
- zero pattern, 30