

## 7 Gaussian Elimination and LU Factorization

In this final section on matrix factorization methods for solving  $Ax = b$  we want to take a closer look at Gaussian elimination (probably the best known method for solving systems of linear equations).

The basic idea is to use left-multiplication of  $A \in \mathbb{C}^{m \times m}$  by (elementary) lower triangular matrices,  $L_1, L_2, \dots, L_{m-1}$  to convert  $A$  to upper triangular form, i.e.,

$$\underbrace{L_{m-1}L_{m-2}\dots L_2L_1}_{=L}A = U.$$

Note that the product of lower triangular matrices is a lower triangular matrix, and the inverse of a lower triangular matrix is also lower triangular. Therefore,

$$\bar{L}A = U \iff A = LU,$$

where  $L = \bar{L}^{-1}$ . This approach can be viewed as *triangular triangularization*.

### 7.1 Why Would We Want to Do This?

Consider the system  $Ax = b$  with LU factorization  $A = LU$ . Then we have

$$L \underbrace{Ux}_{=y} = b.$$

Therefore we can perform (a now familiar) 2-step solution procedure:

1. Solve the lower triangular system  $Ly = b$  for  $y$  by forward substitution.
2. Solve the upper triangular system  $Ux = y$  for  $x$  by back substitution.

Moreover, consider the problem  $AX = B$  (i.e., many different right-hand sides that are associated with the same system matrix). In this case we need to compute the factorization  $A = LU$  only once, and then

$$AX = B \iff LUN = B,$$

and we proceed as before:

1. Solve  $LY = B$  by many forward substitutions (in parallel).
2. Solve  $UN = Y$  by many back substitutions (in parallel).

In order to appreciate the usefulness of this approach note that the operations count for the matrix factorization is  $\mathcal{O}(\frac{2}{3}m^3)$ , while that for forward and back substitution is  $\mathcal{O}(m^2)$ .

**Example** Take the matrix

$$A = \begin{bmatrix} 1 & 1 & 1 \\ 2 & 3 & 5 \\ 4 & 6 & 8 \end{bmatrix}$$

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**Donald G. Fink, Donald Christiansen**



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*Finite-Dimensional Linear Algebra* Mark S. Gockenbach,2010-05-06 This text provides a solid foundation for the study of advanced mathematics and covers many interesting applications of linear algebra which show how linear algebra is essential in such diverse areas as combinatorics differential equations optimization and approximation The book discusses important concepts and methods from numerical linear algebra and contains a range of exercises in each section including some that can be solved using a computer package such as MATLAB It also incorporates mini projects that encourage students to develop topics not covered in the text A forthcoming solutions manual is available for qualifying instructors **An**

**Introduction to Linear Algebra** Ravi P. Agarwal,Elena Cristina Flaut,2017-08-07 The techniques of linear algebra are used extensively across the applied sciences and in many different areas of algebra such as group theory module theory representation theory ring theory and Galois theory Written by experienced researchers with a decades of teaching experience Introduction to Linear Algebra is a clear and rigorous introductory text on this key topic for students of both applied sciences and pure mathematics **Linear Algebra Demystified** David McMahon,2005-10-28 Taught at junior level math courses at every university Linear Algebra is essential for students in almost every technical and analytic discipline

Finite Elements in Water Resources António Sá Costa,1986 *The Linear Complementarity Problem* Richard Cottle,Jong-Shi Pang,Richard E. Stone,1992 During the past twenty years the linear complementarity problem has emerged as an important development in mathematical programming and numerical linear algebra The Linear Complementarity

Problem is a text designed to be suitable for both classroom use and as a references for researchers The book is ideal for graduate students pursuing an advanced degree in operations research but it is also of importance for many related fields of study such as computer science applied mathematics engineering business studies etc

*The Proceedings of the Fourth Conference on Hypercubes, Concurrent Computers, and Applications: Software, applications*, 1989

*Computer Solution of Linear Programs* John Lawrence Nazareth, 1987 This self contained book provides a systematic account of the main algorithms derived from the simplex method and the means by which they may be organized into effective procedures for solving practical linear programming problems on a computer The book begins by characterizing the problem and the method used to solve it going on to deal with the practicalities of the subject emphasizing concerns of implementation The final section of the book discusses the basic principles of optimization duality decomposition and homotopy In conjunction with the simplex method they each lead to other key algorithms of linear programming The author s approach is distinguished by his detailed exploration of ideas and issues that center on the need to structure data suitably and to organize calculations in an efficient and numerically stable manner Unlike many liner programming texts the author s overall perspective is grounded in nonlinear programming rather than combinatorics

*SIAM Journal on Matrix Analysis and Applications*, 1998

Numerical Analysis David Ronald Kincaid, Elliott Ward Cheney, 1996 This work treats numerical analysis from a mathematical point of view demonstrating that the many computational algorithms and intriguing questions of computer science arise from theorems and proofs Algorithms are developed in pseudocode with the intention of making it easy for students to write computer routines in a number of standard programming languages including BASIC Fortran C and Pascal

**Electronics Engineers' Handbook** Donald G. Fink, Donald Christiansen, 1989 Very Good No Highlights or Markup all pages are intact

*Fundamentals of Matrix Computations* David S. Watkins, 1991-01-16 The use of numerical methods continues to expand rapidly At their heart lie matrix computations Written in a clear expository style it allows students and professionals to build confidence in themselves by putting the theory behind matrix computations into practice instantly Algorithms that allow students to work examples and write programs introduce each chapter The book then moves on to discuss more complicated theoretical material Using a step by step approach it introduces mathematical material only as it is needed Exercises range from routine computations and verifications to extensive programming projects and challenging proofs

Parallel Computing Technologies, 2003

**Modern Matrix Algebra** David Ross Hill, Bernard Kolman, 2001 A recapitulation of his earlier work Seeds of Contemplation this collection of sixteen essays plumbs aspects of human spirituality Merton addresses those in search of enduring values fulfillment and salvation in prose that is as always inspiring and compassionate A stimulating series of spiritual reflections which will prove helpful for all struggling to live the richest fullest and noblest life Chicago Tribune

*Linear Algebra* David Poole, 2005 David Poole s innovative book emphasizes vectors and geometric intuition from the start and better prepares students to make the transition from the

computational aspects of the course to the theoretical Poole covers vectors and vector geometry first to enable students to visualize the mathematics while they are doing matrix operations With a concrete understanding of vector geometry students are able to visualize and understand the meaning of the calculations that they will encounter By seeing the mathematics and understanding the underlying geometry students develop mathematical maturity and can think abstractly when they reach vector spaces Throughout the text Poole s direct conversational writing style connects with students and an abundant selection of applications from a broad range of disciplines clearly demonstrates the relevance of linear algebra SIAM Journal on Scientific and Statistical Computing Society for Industrial and Applied Mathematics,1992 *PSCC Proceedings*,1969 **7th Mediterranean Electrotechnical Conference** Önder Yüksel,1994 **Computer Application Advances in the Electric Power Industry** ,1974 **Applied Numerical Methods** University of Michigan. Engineering Summer Conferences,1987

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