

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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