Linear Algebra Cheat Sheet
Inverse Matrix

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January 2024

1 Properties of Inverse Matrix

- $AA^{-1} = I$, $A^{-1}A = I$
- $(A^T)^{-1} = (A^{-1})^T$
- $(AB)^{-1} = B^{-1}A^{-1}$

Question 1 If A and M have inverse matrix A^{-1} and M^{-1} and

X, Y, Z are matrix!

- $AX = B$ $\quad A^{-1}(AX) = A^{-1}B \Rightarrow X = IX = A^{-1}B$
- $YM = C$ $\quad (YM)M^{-1} = CM^{-1} \Rightarrow Y = YI = CM^{-1}$
- $AZM^T = D$ $\quad M^T$ is invertible. $(M^T)^{-1} = (M^{-1})^T$

what is X, Y, Z?

$A^{-1}(AZM^T)(M^T)^{-1} = A^{-1}D(M^T)^{-1} \Rightarrow Z = I\cdot Z\cdot I = A^{-1}\cdot D\cdot (M^T)^{-1} = A^{-1}D(M^{-1})^T$

$E_{ji} = \begin{bmatrix} 1 & & \\ a_{ji} & \ddots & \\ & & 1 \end{bmatrix}$

!!!

$E_{ji}^{-1} = \begin{bmatrix} 1 & & \\ -a_{ji} & \ddots & \\ & & 1 \end{bmatrix}$

2 Elimination

Elimination as Matrix Operation We can write the operations to change equivalent linear system by $[A|b] \to [E_{ij}A|E_{ij}b]$ and $[P_{ij}A|P_{ij}b]$.

- Elimination matrix E_{ij}:
  - Replace row (j) by $*$*row(i) + row (j) ← $[E_{ij}A \,|\, E_{ij}b]$
  - Identity matrix except $a_{ij} = *$
- Permutation matrix P_{ij}:
  - Swtich Row (i) with Row (j) ← $[P_{ij}A \,|\, P_{ij}b]$
  - Identity matrix except $a_{ij} = a_{ji} = 1, a_{ii} = a_{jj} = 0$

$\begin{bmatrix} 1 & & \\ * a_{ij} & \ddots & \\ & & 1 \end{bmatrix}$

ex. $E_{32}E_{31}E_{21}A$ ③ ② ①

1. Operate E_{21} first
2. Then Operate E_{31}
3. Final Operate E_{32}

$E_{21} = \begin{bmatrix} 1 & & \\ 2 & 1 & \\ & & \ddots \; 1 \end{bmatrix}$

$E_{21}^{-1} = \begin{bmatrix} 1 & & \\ -2 & 1 & \\ & & \ddots \; 1 \end{bmatrix}$

Question 2 What is the matrix after the following operations

- Change Row 2 of A to Row 2 + 2* Row 1 $\quad E_{21}$ ①
- Switch Row 3 and Row 4 of the new matrix $\quad P_{34}$ ② → $P_{34}(E_{21}A)$
- Change Row 4 of the new matrix to Row 4 + 2* Row 2 $\quad E_{42}$ ③ → $E_{42}(P_{34}(E_{21}A))$

$A \to E_{21}A \to P_{34}(E_{21}A)$

3 Inverse Matrix

- The inverse of a matrix exists if and only if the matrix is a square matrix and all column vectors are linear independent.
- The inverse of a matrix exists if and only if elimination produced n non-zero pivots.

Questions (answer is in the slide) Can you describe how the upper triangular form and their pivots look like for the following three cases

- The linear system have a single solution
- The linear system have no solution
- The linear system have infinite solutions

Questions Please ensure you know the answer of the following questions

- How to calculate the inverse of a matrix?
- What is the inverse of the elimination matrix? What is the inverse of the permutation matrix?

① Single Solution. n non-zero pivot

$$\left[\begin{array}{cccc|c} * & \times & \cdots & \times & \times \\ & * & \ddots & \times & \times \\ & & & & \vdots \\ & & & * & \times \end{array}\right]$$

$*$: non-zero
$\times$: any number

② No Solution

pivot is zero → $\left[\begin{array}{ccc|c} 0 & \cdots & 0 & \triangle \end{array}\right]$ $\triangle$: non-zero value $0x_1 + \cdots + 0x_n = \triangle$, not possible!!

③ Infinite Solution.

$\left[\begin{array}{ccc|c} 0 & \cdots & 0 & -1 \\ 0 & \cdots & 0 & 0 \end{array}\right]$ ↑ no solution!!

1. have a row $0 \cdots 0 \mid 0$
2. all the row. whose left part is all zero $0 \cdots 0$ the right part is also 0!!!

LU Decomposition!

$$A = \underset{\text{lower Traingular}}{L} \cdot U \leftarrow \text{upper Traingular}$$

LDU Decomposition

$$A = L \; D \; U$$

D: diagnal Matrix

U: upper Traingular but all 1 on the diag

L: Lower Traingular but all 1 on the diag

if A is symmetric

$$A = L \cdot D \cdot L^T$$

(LDL decomposition)

1. LDU, LDL are Unique!!
2. LU is not unique.

$A = L_1 U_1 = L_2 U_2$

Then $L_1 = L_2 \cdot \underset{=}{\overset{\text{diag}}{D}}$ (!)

1. LDU Decomposition is Unique!!!

Let's assume $A = L_1 U_1 = L_2 \cdot U_2$

$\Rightarrow \underbrace{L_2^{-1} \cdot L_1}_{\text{L.T.}} = \underbrace{U_2 \cdot U_1^{-1}}_{\text{U.T.}}$

$L_2^{-1} L_1 U_1 \cancel{U_1^{-1}} = \cancel{L_2^{-1}} L_2 U_2 U_2^{-1}$

① Inverse of Lower Traingular is L.T.

② L.T. × L.T. → L.T.

$\rightarrow$ $L_2^{-1} \cdot L_1$ or $U_2 \cdot U_1^{-1}$ are both L.T. and U.T. means. They are diag!!!

$$L_2^{-1} \cdot L_1 = \overset{\text{diagnal}}{D} = U_2 \cdot U_1^{-1}$$

$L_1 = L_2 \cdot D$ $\quad L_2 (L_2^{-1} L_1) = L_2 \cdot D$

$U_2 = D \cdot U_1$ $\quad D \cdot U_1 = (U_2 \cdot U_1^{-1}) U_1$

if diag of L_2 and L_1 are 1. then my D is identity

hint!! $L_1 = L_2 \cdot D$

$\Rightarrow (L_1)_{11} = (L_2)_{11} \cdot d_{11} \Rightarrow d_{11} = 1 \Rightarrow$ D is identity!!