

Elementary Matrix

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Gauss-Jordan Elimination

Forward Phase - Gaussian Elimination

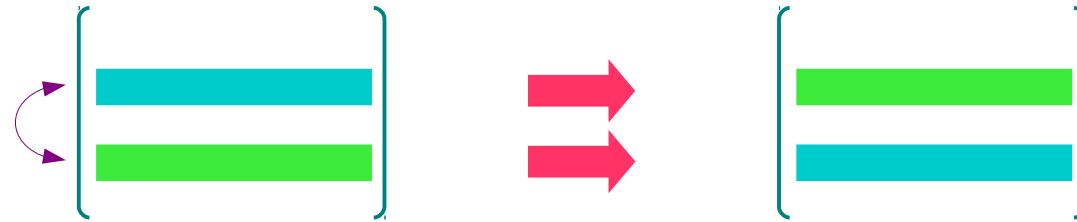
$$\begin{array}{c}
 \left(\begin{array}{ccc|c}
 \textcircled{+2} & +1 & -1 & +8 \\
 -3 & -1 & +2 & -11 \\
 -2 & +1 & +2 & -3
 \end{array} \right) \rightarrow \left(\begin{array}{ccc|c}
 \textcircled{+1} & +1/2 & -1/2 & +4 \\
 -3 & -1 & +2 & -11 \\
 -2 & +1 & +2 & -3
 \end{array} \right) \rightarrow \left(\begin{array}{ccc|c}
 +1 & +1/2 & -1/2 & +4 \\
 \boxed{0} & +1/2 & +1/2 & +1 \\
 \boxed{0} & +2 & +1 & +5
 \end{array} \right) \\
 \\
 \left(\begin{array}{ccc|c}
 +1 & +1/2 & -1/2 & +4 \\
 0 & \textcircled{+1} & +1 & +2 \\
 0 & +2 & +1 & +5
 \end{array} \right) \rightarrow \left(\begin{array}{ccc|c}
 +1 & +1/2 & -1/2 & +4 \\
 0 & +1 & +1 & +2 \\
 0 & \boxed{0} & -1 & +1
 \end{array} \right) \rightarrow \left(\begin{array}{ccc|c}
 +1 & +1/2 & -1/2 & +4 \\
 0 & +1 & +1 & +2 \\
 0 & 0 & \textcircled{+1} & -1
 \end{array} \right)
 \end{array}$$

Backward Phase

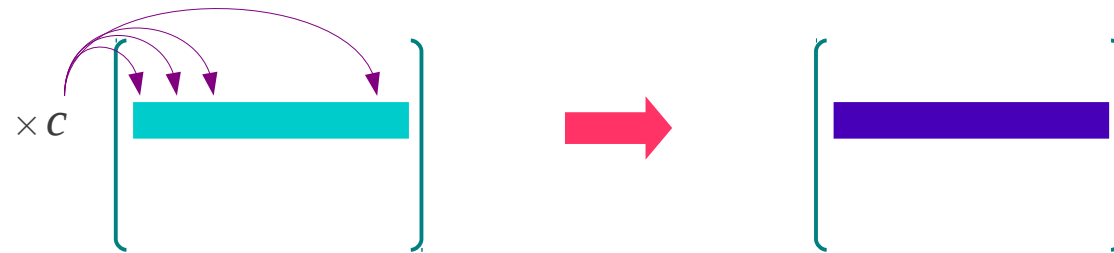
$$\begin{array}{c}
 \left(\begin{array}{ccc|c}
 +1 & +1/2 & \boxed{-1/2} & +4 \\
 0 & +1 & \boxed{+1} & +2 \\
 0 & 0 & +1 & -1
 \end{array} \right) \rightarrow \left(\begin{array}{ccc|c}
 +1 & +1/2 & \boxed{0} & +7/2 \\
 0 & +1 & \boxed{0} & +3 \\
 0 & 0 & +1 & -1
 \end{array} \right) \rightarrow \left(\begin{array}{ccc|c}
 +1 & \boxed{0} & \boxed{0} & +2 \\
 0 & +1 & \boxed{0} & +3 \\
 0 & 0 & +1 & -1
 \end{array} \right)
 \end{array}$$

Elementary Row Operation

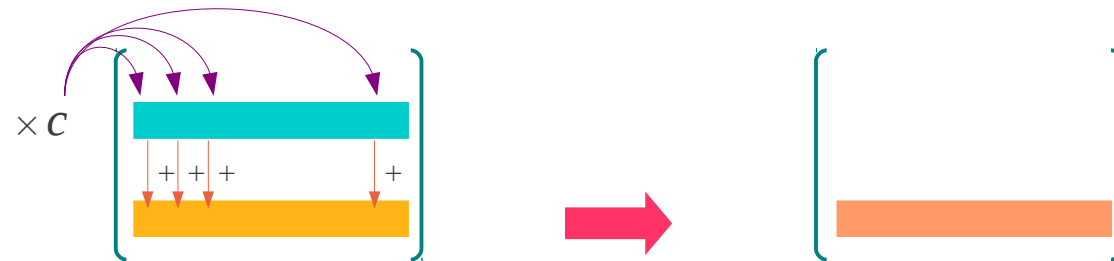
Interchange two rows



Multiply a row by a nonzero constant



Add a multiple of one row to another



Elementary Matrix

Identity Matrix

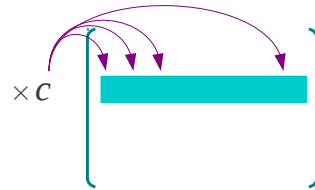
$$\begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

Interchange two rows



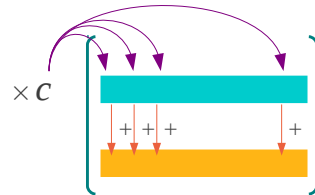
$$\begin{pmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

Multiply a row by a nonzero constant



$$\begin{pmatrix} 3 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

Add a multiple of one row to another



$$\begin{pmatrix} 1 & 0 & 0 \\ 4 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

Multiplication by an Elementary Matrix

$$\begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$\begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \\ 7 & 8 & 9 \end{bmatrix}$$

$$\begin{bmatrix} 4 & 5 & 6 \\ 1 & 2 & 3 \\ 7 & 8 & 9 \end{bmatrix}$$

$$\begin{bmatrix} 3 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$\begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \\ 7 & 8 & 9 \end{bmatrix}$$

$$\begin{bmatrix} 3 & 6 & 9 \\ 4 & 5 & 6 \\ 7 & 8 & 9 \end{bmatrix}$$

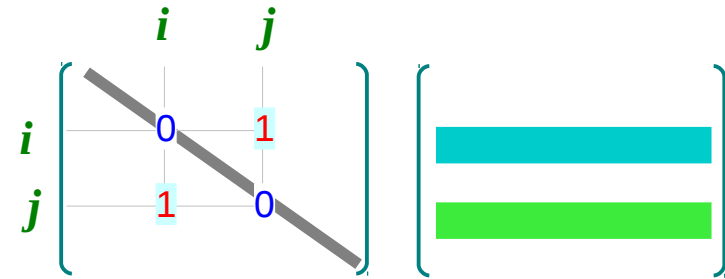
$$\begin{bmatrix} 1 & 0 & 0 \\ 4 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$\begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \\ 7 & 8 & 9 \end{bmatrix}$$

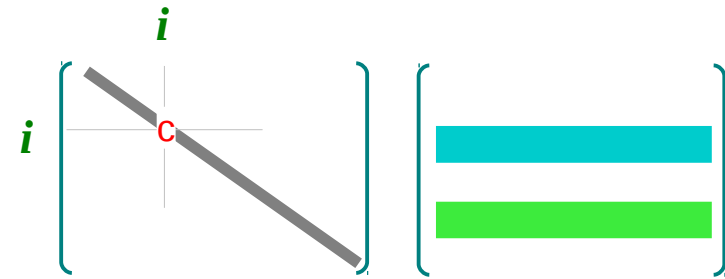
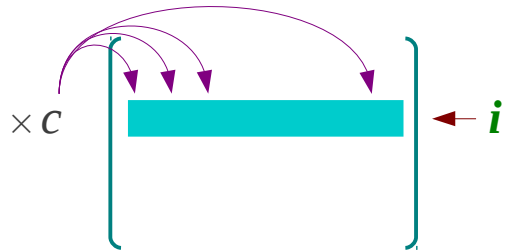
$$\begin{bmatrix} 1 & 2 & 3 \\ 8 & 13 & 18 \\ 7 & 8 & 9 \end{bmatrix}$$

Elementary Matrix

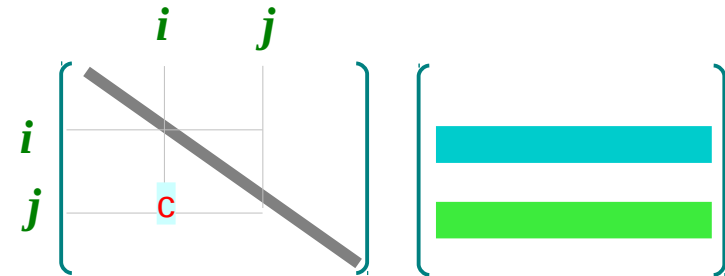
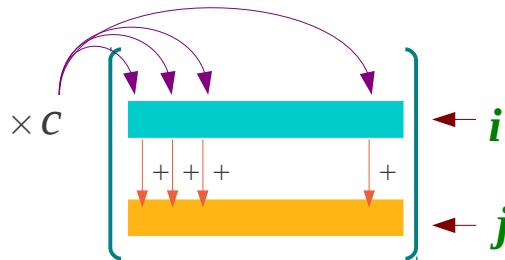
Interchange two rows



Multiply a row by a nonzero constant



Add a multiple of one row to another



Gauss-Jordan Elimination – Step 1

$$\begin{array}{lcl} +2x_1 + x_2 - x_3 = 8 & (L_1) & \\ -3x_1 - x_2 + 2x_3 = -11 & (L_2) & \\ -2x_1 + x_2 + 2x_3 = -3 & (L_3) & \end{array} \left[\begin{array}{ccc|c} +2 & +1 & -1 & +8 \\ -3 & -1 & +2 & -11 \\ -2 & +1 & +2 & -3 \end{array} \right]$$

$$\left[\begin{array}{ccc} 1/2 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{array} \right] \left[\begin{array}{ccc|c} +2 & +1 & -1 & +8 \\ -3 & -1 & +2 & -11 \\ -2 & +1 & +2 & -3 \end{array} \right]$$

$$\begin{array}{lcl} +1x_1 + \frac{1}{2}x_2 - \frac{1}{2}x_3 = 4 & (\frac{1}{2} \times L_1) & \\ -3x_1 - x_2 + 2x_3 = -11 & (L_2) & \\ -2x_1 + x_2 + 2x_3 = -3 & (L_3) & \end{array} \left[\begin{array}{ccc|c} +1 & +1/2 & -1/2 & +4 \\ -3 & -1 & +2 & -11 \\ -2 & +1 & +2 & -3 \end{array} \right]$$

Gauss-Jordan Elimination – Step 2

$$\begin{array}{lcl}
 +1x_1 + \frac{1}{2}x_2 - \frac{1}{2}x_3 = +4 & (L_1) & \\
 -3x_1 - x_2 + 2x_3 = -11 & (L_2) & \\
 -2x_1 + x_2 + 2x_3 = -3 & (L_3) &
 \end{array}
 \quad
 \left[\begin{array}{ccc|c}
 +1 & +1/2 & -1/2 & +4 \\
 -3 & -1 & +2 & -11 \\
 -2 & +1 & +2 & -3
 \end{array} \right]$$

$$\left[\begin{array}{ccc}
 1 & 0 & 0 \\
 0 & 1 & 0 \\
 2 & 0 & 1
 \end{array} \right]
 \quad
 \left[\begin{array}{ccc}
 1 & 0 & 0 \\
 3 & 1 & 0 \\
 0 & 0 & 1
 \end{array} \right]
 \quad
 \left[\begin{array}{ccc|c}
 +1 & +1/2 & -1/2 & +4 \\
 -3 & -1 & +2 & -11 \\
 -2 & +1 & +2 & -3
 \end{array} \right]$$

$$\begin{array}{lcl}
 +1x_1 + \frac{1}{2}x_2 - \frac{1}{2}x_3 = +4 & (L_1) & \\
 0x_1 + \frac{1}{2}x_2 + \frac{1}{2}x_3 = +1 & (3 \times L_1 + L_2) & \\
 0x_1 + 2x_2 + 1x_3 = +5 & (2 \times L_1 + L_3) &
 \end{array}
 \quad
 \left[\begin{array}{ccc|c}
 +1 & +1/2 & -1/2 & +4 \\
 0 & +1/2 & +1/2 & +1 \\
 0 & +2 & +1 & +5
 \end{array} \right]$$

Gauss-Jordan Elimination – Step 3

$$\begin{array}{lcl}
 +1x_1 + \frac{1}{2}x_2 - \frac{1}{2}x_3 = +4 & (L_1) & \\
 0x_1 + \frac{1}{2}x_2 + \frac{1}{2}x_3 = +1 & (L_2) & \\
 0x_1 + 2x_2 + 1x_3 = +5 & (L_3) &
 \end{array}
 \left[\begin{array}{ccc|c}
 +1 & +1/2 & -1/2 & +4 \\
 0 & +1/2 & +1/2 & +1 \\
 0 & +2 & +1 & +5
 \end{array} \right]$$

$$\left[\begin{array}{ccc}
 1 & 0 & 0 \\
 0 & 2 & 0 \\
 0 & 0 & 1
 \end{array} \right]
 \left[\begin{array}{ccc|c}
 +1 & +1/2 & -1/2 & +4 \\
 0 & +1/2 & +1/2 & +1 \\
 0 & +2 & +1 & +5
 \end{array} \right]$$

$$\begin{array}{lcl}
 +1x_1 + \frac{1}{2}x_2 - \frac{1}{2}x_3 = +4 & (L_1) & \\
 0x_1 + 1x_2 + 1x_3 = +2 & (2 \times L_2) & \\
 0x_1 + 2x_2 + 1x_3 = +5 & (L_3) &
 \end{array}
 \left[\begin{array}{ccc|c}
 +1 & +1/2 & -1/2 & +4 \\
 0 & +1 & +1 & +2 \\
 0 & +2 & +1 & +5
 \end{array} \right]$$

Gauss-Jordan Elimination – Step 4

$$\begin{array}{lcl}
 +1x_1 + \frac{1}{2}x_2 - \frac{1}{2}x_3 = +4 & (L_1) & \\
 0x_1 + 1x_2 + 1x_3 = +2 & (L_2) & \\
 0x_1 + 2x_2 + 1x_3 = +5 & (L_3) &
 \end{array}
 \left[\begin{array}{ccc|c}
 +1 & +1/2 & -1/2 & +4 \\
 0 & +1 & +1 & +2 \\
 0 & +2 & +1 & +5
 \end{array} \right]$$

$$\left[\begin{array}{ccc}
 1 & 0 & 0 \\
 0 & 1 & 0 \\
 0 & -2 & 1
 \end{array} \right]
 \left[\begin{array}{ccc|c}
 +1 & +1/2 & -1/2 & +4 \\
 0 & +1 & +1 & +2 \\
 0 & +2 & +1 & +5
 \end{array} \right]$$

$$\begin{array}{lcl}
 +1x_1 + \frac{1}{2}x_2 - \frac{1}{2}x_3 = +4 & (L_1) & \\
 0x_1 + 1x_2 + 1x_3 = +2 & (L_2) & \\
 0x_1 + 0x_2 - 1x_3 = +1 & (-2 \times L_2 + L_3) &
 \end{array}
 \left[\begin{array}{ccc|c}
 +1 & +1/2 & -1/2 & +4 \\
 0 & +1 & +1 & +2 \\
 0 & 0 & -1 & +1
 \end{array} \right]$$

Gauss-Jordan Elimination – Step 5

$$+1x_1 + \frac{1}{2}x_2 - \frac{1}{2}x_3 = +4 \quad (L_1)$$

$$0x_1 + 1x_2 + 1x_3 = +2 \quad (L_2)$$

$$0x_1 + 0x_2 - 1x_3 = +1 \quad (L_3)$$

$$\left[\begin{array}{ccc|c} +1 & +1/2 & -1/2 & +4 \\ 0 & +1 & +1 & +2 \\ 0 & 0 & -1 & +1 \end{array} \right]$$

$$\left[\begin{array}{ccc} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -1 \end{array} \right]$$

$$\left[\begin{array}{ccc|c} +1 & +1/2 & -1/2 & +4 \\ 0 & +1 & +1 & +2 \\ 0 & 0 & -1 & +1 \end{array} \right]$$

$$+1x_1 + \frac{1}{2}x_2 - \frac{1}{2}x_3 = +4 \quad (L_1)$$

$$0x_1 + 1x_2 + 1x_3 = +2 \quad (L_2)$$

$$0x_1 + 0x_2 + 1x_3 = -1 \quad (-1 \times L_3)$$

$$\left[\begin{array}{ccc|c} +1 & +1/2 & -1/2 & +4 \\ 0 & +1 & +1 & +2 \\ 0 & 0 & +1 & -1 \end{array} \right]$$

Forward Phase

$$\begin{array}{c}
 \left(\begin{array}{ccc|c}
 \textcircled{+2} & +1 & -1 & +8 \\
 -3 & -1 & +2 & -11 \\
 -2 & +1 & +2 & -3
 \end{array} \right) \rightarrow \left(\begin{array}{ccc|c}
 \textcircled{+1} & +1/2 & -1/2 & +4 \\
 -3 & -1 & +2 & -11 \\
 -2 & +1 & +2 & -3
 \end{array} \right) \rightarrow \left(\begin{array}{ccc|c}
 +1 & +1/2 & -1/2 & +4 \\
 \boxed{0} & +1/2 & +1/2 & +1 \\
 \boxed{0} & +2 & +1 & +5
 \end{array} \right) \rightarrow \\
 \left(\begin{array}{ccc|c}
 +1 & +1/2 & -1/2 & +4 \\
 0 & \textcircled{+1} & +1 & +2 \\
 0 & +2 & +1 & +5
 \end{array} \right) \rightarrow \left(\begin{array}{ccc|c}
 +1 & +1/2 & -1/2 & +4 \\
 0 & +1 & +1 & +2 \\
 0 & \boxed{0} & -1 & +1
 \end{array} \right) \rightarrow \left(\begin{array}{ccc|c}
 +1 & +1/2 & -1/2 & +4 \\
 0 & +1 & +1 & +2 \\
 0 & 0 & \textcircled{+1} & -1
 \end{array} \right)
 \end{array}$$

Forward Phase - Gaussian Elimination

Gauss-Jordan Elimination – Step 6

$$\begin{array}{lcl}
 +1x_1 + \frac{1}{2}x_2 - \frac{1}{2}x_3 = +4 & (L_1) & \\
 0x_1 + 1x_2 + 1x_3 = +2 & (L_2) & \\
 0x_1 + 0x_2 + 1x_3 = -1 & (L_3) &
 \end{array}
 \left[\begin{array}{ccc|c}
 +1 & +1/2 & -1/2 & +4 \\
 0 & +1 & +1 & +2 \\
 0 & 0 & +1 & -1
 \end{array} \right]$$

$$\left[\begin{array}{ccc}
 1 & 0 & 0 \\
 0 & 1 & -1 \\
 0 & 0 & 1
 \end{array} \right]
 \left[\begin{array}{ccc}
 1 & 0 & 1/2 \\
 0 & 1 & 0 \\
 0 & 0 & 1
 \end{array} \right]
 \left[\begin{array}{ccc|c}
 +1 & +1/2 & -1/2 & +4 \\
 0 & +1 & +1 & +2 \\
 0 & 0 & +1 & -1
 \end{array} \right]$$

$$\begin{array}{lcl}
 +1x_1 + \frac{1}{2}x_2 + 0x_3 = +\frac{7}{2} & (+\frac{1}{2} \times L_3 + L_1) & \\
 0x_1 + 1x_2 + 0x_3 = +3 & (-1 \times L_3 + L_2) & \\
 0x_1 + 0x_2 + 1x_3 = -1 & (L_3) &
 \end{array}
 \left[\begin{array}{ccc|c}
 +1 & +1/2 & 0 & +7/2 \\
 0 & +1 & 0 & +3 \\
 0 & 0 & +1 & -1
 \end{array} \right]$$

Gauss-Jordan Elimination – Step 7

$$\begin{array}{rcl}
 +1x_1 + \frac{1}{2}x_2 + 0x_3 = +\frac{7}{2} & (L_1) & \\
 0x_1 + 1x_2 + 0x_3 = +3 & (L_2) & \\
 0x_1 + 0x_2 + 1x_3 = -1 & (L_3) &
 \end{array}
 \left[\begin{array}{ccc|c}
 +1 & +1/2 & 0 & +7/2 \\
 0 & +1 & 0 & +3 \\
 0 & 0 & +1 & -1
 \end{array} \right]$$

$$\left[\begin{array}{ccc}
 1 & -1/2 & 0 \\
 0 & 1 & 0 \\
 0 & 0 & 1
 \end{array} \right]
 \left[\begin{array}{ccc|c}
 +1 & +1/2 & 0 & +7/2 \\
 0 & +1 & 0 & +3 \\
 0 & 0 & +1 & -1
 \end{array} \right]$$

$$\begin{array}{rcl}
 +1x_1 + 0x_2 - 0x_3 = +2 & (-\frac{1}{2} \times L_2 + L_1) & \\
 0x_1 + 1x_2 + 0x_3 = +3 & (L_2) & \\
 0x_1 + 0x_2 + 1x_3 = -1 & (L_3) &
 \end{array}
 \left[\begin{array}{ccc|c}
 +1 & 0 & 0 & +2 \\
 0 & +1 & 0 & +3 \\
 0 & 0 & +1 & -1
 \end{array} \right]$$

Backward Phase

$$\left(\begin{array}{ccc|c} +1 & +1/2 & -1/2 & +4 \\ 0 & +1 & +1 & +2 \\ 0 & 0 & +1 & -1 \end{array} \right) \rightarrow \left(\begin{array}{ccc|c} +1 & +1/2 & 0 & +7/2 \\ 0 & +1 & 0 & +3 \\ 0 & 0 & +1 & -1 \end{array} \right) \rightarrow \left(\begin{array}{ccc|c} +1 & 0 & 0 & +2 \\ 0 & +1 & 0 & +3 \\ 0 & 0 & +1 & -1 \end{array} \right) \rightarrow$$

Gauss-Jordan Elimination

Forward Phase - Gaussian Elimination

$$\left(\begin{array}{ccc|c} \textcircled{+2} & +1 & -1 & +8 \\ -3 & -1 & +2 & -11 \\ -2 & +1 & +2 & -3 \end{array} \right) \rightarrow \left(\begin{array}{ccc|c} \textcircled{+1} & +1/2 & -1/2 & +4 \\ -3 & -1 & +2 & -11 \\ -2 & +1 & +2 & -3 \end{array} \right) \rightarrow \left(\begin{array}{ccc|c} +1 & +1/2 & -1/2 & +4 \\ \boxed{0} & +1/2 & +1/2 & +1 \\ \boxed{0} & +2 & +1 & +5 \end{array} \right) \rightarrow$$

$$\left(\begin{array}{ccc|c} +1 & +1/2 & -1/2 & +4 \\ 0 & \textcircled{+1} & +1 & +2 \\ 0 & +2 & +1 & +5 \end{array} \right) \rightarrow \left(\begin{array}{ccc|c} +1 & +1/2 & -1/2 & +4 \\ 0 & +1 & +1 & +2 \\ 0 & \boxed{0} & -1 & +1 \end{array} \right) \rightarrow \left(\begin{array}{ccc|c} +1 & +1/2 & -1/2 & +4 \\ 0 & +1 & +1 & +2 \\ 0 & 0 & \textcircled{+1} & -1 \end{array} \right) \rightarrow$$

Backward Phase

$$\left(\begin{array}{ccc|c} +1 & +1/2 & \boxed{-1/2} & +4 \\ 0 & +1 & \boxed{+1} & +2 \\ 0 & 0 & +1 & -1 \end{array} \right) \rightarrow \left(\begin{array}{ccc|c} +1 & +1/2 & \boxed{0} & +7/2 \\ 0 & +1 & \boxed{0} & +3 \\ 0 & 0 & +1 & -1 \end{array} \right) \rightarrow \left(\begin{array}{ccc|c} +1 & \boxed{0} & \boxed{0} & +2 \\ 0 & +1 & \boxed{0} & +3 \\ 0 & 0 & +1 & -1 \end{array} \right) \rightarrow$$

Equivalent Statements

A : invertible

$$\begin{bmatrix} A \\ \text{cyan square} \end{bmatrix} \begin{bmatrix} A^{-1} \\ \text{green square} \end{bmatrix} = \begin{bmatrix} A^{-1} \\ \text{green square} \end{bmatrix} \begin{bmatrix} A \\ \text{cyan square} \end{bmatrix} = \begin{bmatrix} I_n \\ \text{identity matrix} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

$Ax = 0$
only the trivial solution

$$\begin{bmatrix} A \\ \text{cyan square} \end{bmatrix} \begin{bmatrix} x \\ \text{orange column} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$

A the RREF is I_n
(Reduced Row Echelon Form)

$$\begin{bmatrix} A \\ \text{cyan square} \end{bmatrix} \xrightarrow{\text{Elem Row Op}} \begin{bmatrix} I_n \\ \text{identity matrix} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

A can be written as a product of E_k
(Elementary Matrices)

$$\begin{matrix} i & j \\ \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} \\ j \end{matrix} \quad \begin{matrix} i \\ \begin{bmatrix} c \\ \text{row } i \end{bmatrix} \end{matrix} \quad \begin{matrix} i & j \\ \begin{bmatrix} c \\ \text{row } j \end{bmatrix} \\ j \end{matrix}$$

Proof (1)

A : invertible

$$\begin{bmatrix} A \\ \text{cyan square} \end{bmatrix} \begin{bmatrix} A^{-1} \\ \text{green square} \end{bmatrix} = \begin{bmatrix} A^{-1} \\ \text{green square} \end{bmatrix} \begin{bmatrix} A \\ \text{cyan square} \end{bmatrix} = \begin{bmatrix} I_n \\ \text{identity matrix} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

$Ax = 0$
only the trivial solution

$$\begin{bmatrix} A \\ \text{cyan square} \end{bmatrix} \begin{bmatrix} x \\ \text{orange column} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$

A : invertible
 x_0 a solution of $Ax = 0$ }

$$Ax_0 = 0$$

$$A^{-1}Ax_0 = A^{-1}0$$

$$I_n x_0 = 0$$

$$x_0 = 0 \quad \text{trivial}$$

Proof (2)

$$Ax = 0$$

only the **trivial** solution

$$A \quad x = 0$$

$$\left[\begin{array}{c} \square \\ \square \\ \square \end{array} \right] \left[\begin{array}{c} \square \\ \square \end{array} \right] = \left[\begin{array}{c} 0 \\ 0 \\ 0 \end{array} \right]$$

A the RREF is I_n
(Reduced Row Echelon Form)

$$A \xrightarrow{\text{Elem Row Op}} I_n$$

$$\left[\begin{array}{c} \square \\ \square \end{array} \right] \rightarrow \left[\begin{array}{cc} 1 & 0 \\ 0 & 1 \end{array} \right]$$

only the **trivial** solution

After the forward and backward phases of Gauss-Jordan Elimination

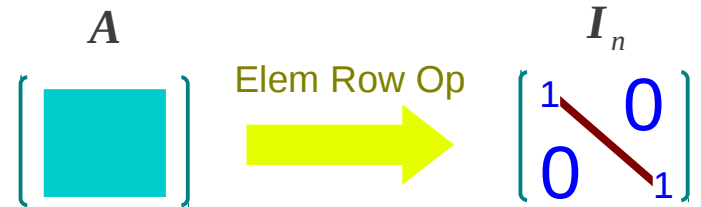
$$\left(\begin{array}{cccc|c} 1 & 0 & \dots & 0 & 0 \\ 0 & 1 & \dots & 0 & 0 \\ \vdots & \vdots & & \vdots & \vdots \\ 0 & 0 & \dots & 1 & 0 \end{array} \right)$$

$$\begin{array}{l} a_{11}x_1 + a_{12}x_2 + \dots + a_{1n}x_n = 0 \\ a_{21}x_1 + a_{22}x_2 + \dots + a_{2n}x_n = 0 \\ \vdots \\ a_{m1}x_1 + a_{m2}x_2 + \dots + a_{mn}x_n = 0 \end{array}$$

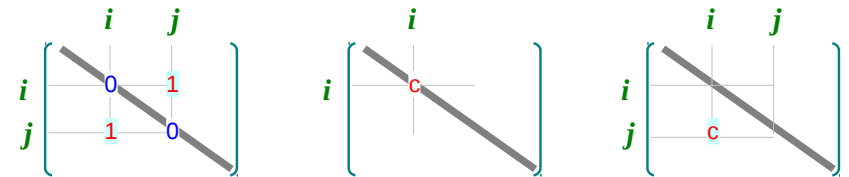
$$\begin{array}{l} 1x_1 = 0 \\ \quad + 1x_2 = 0 \\ \quad \quad \quad \vdots \\ 1x_n = 0 \end{array}$$

Proof (3)

A the RREF is I_n
(Reduced Row Echelon Form)



A can be written as a product of E_k
(Elementary Matrices)



$$E_k \cdots E_2 E_1 A = I_n$$



$$E_{k-1} \cdots E_2 E_1 A = E_k^{-1}$$



$$A = E_1^{-1} E_2^{-1} \cdots E_k^{-1}$$

$$E_k^{-1} E_k E_{k-1} \cdots E_2 E_1 A = E_k^{-1} I_n$$

$$E_{k-1}^{-1} E_{k-1} \cdots E_2 E_1 A = E_{k-1}^{-1} E_k^{-1}$$

(Elementary Matrices)

Proof (4)

A can be written as a product of E_k
(Elementary Matrices)

A : invertible

$$\begin{bmatrix} A \\ \text{[cyan square]} \end{bmatrix} \begin{bmatrix} A^{-1} \\ \text{[green square]} \end{bmatrix} = \begin{bmatrix} A^{-1} \\ \text{[green square]} \end{bmatrix} \begin{bmatrix} A \\ \text{[cyan square]} \end{bmatrix} = \begin{bmatrix} I_n \\ \text{[red diagonal]} \end{bmatrix}$$

$$E_k \cdots E_2 E_1 A = I_n$$

$$A^{-1} A = I_n$$

$$A^{-1} = E_k \cdots E_2 E_1$$

Inversion Algorithm (1)

$$\begin{array}{c}
 \mathbf{A} \\
 \left[\begin{array}{c} \text{cyan square} \end{array} \right]
 \end{array}
 \begin{array}{c}
 \mathbf{A}^{-1} \\
 \left[\begin{array}{c} \text{green square} \\ \text{blue vertical lines} \end{array} \right] \\
 \begin{array}{c} \swarrow \quad \searrow \quad \searrow \\ \mathbf{x}_1 \mid \mathbf{x}_2 \mid \cdots \mid \mathbf{x}_n \end{array}
 \end{array}
 =
 \begin{array}{c}
 \left[\begin{array}{c} \text{cyan square} \\ \text{blue vertical lines} \end{array} \right] \\
 \begin{array}{c} \swarrow \quad \searrow \quad \searrow \\ \mathbf{b}_1 \mid \mathbf{b}_2 \mid \cdots \mid \mathbf{b}_n \end{array}
 \end{array}$$

$$\begin{array}{c}
 \mathbf{A} \\
 \left[\begin{array}{c} \text{cyan square} \end{array} \right]
 \end{array}
 \begin{array}{c}
 \mathbf{x}_1 \\
 \left[\begin{array}{c} \text{green vertical bar} \end{array} \right]
 \end{array}
 =
 \begin{array}{c}
 \mathbf{b}_1 \\
 \left[\begin{array}{c} 1 \\ 0 \\ 0 \end{array} \right]
 \end{array}$$

$$\begin{array}{c}
 \mathbf{A} \\
 \left[\begin{array}{c} \text{cyan square} \end{array} \right]
 \end{array}
 \begin{array}{c}
 \mathbf{x}_n \\
 \left[\begin{array}{c} \text{green vertical bar} \end{array} \right]
 \end{array}
 =
 \begin{array}{c}
 \mathbf{b}_n \\
 \left[\begin{array}{c} 0 \\ 0 \\ 1 \end{array} \right]
 \end{array}$$

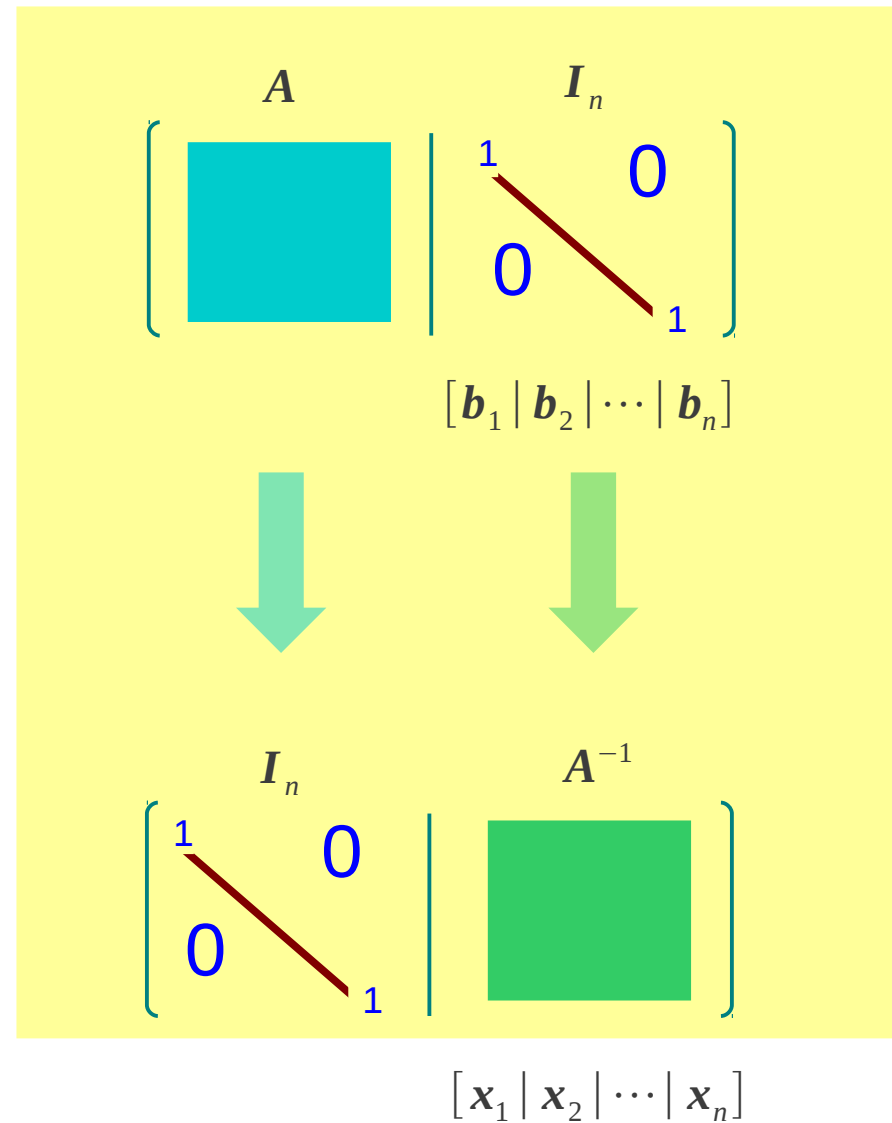
$$\begin{array}{c}
 \mathbf{A} \\
 \left[\begin{array}{c} \text{cyan square} \end{array} \right]
 \end{array}
 \begin{array}{c}
 \mathbf{x}_2 \\
 \left[\begin{array}{c} \text{green vertical bar} \end{array} \right]
 \end{array}
 =
 \begin{array}{c}
 \mathbf{b}_2 \\
 \left[\begin{array}{c} 0 \\ 1 \\ 0 \end{array} \right]
 \end{array}$$

Inversion Algorithm (2)

$$\left[\begin{array}{c|c} A & \mathbf{x}_1 \\ \hline \end{array} \right] = \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$$

$$\left[\begin{array}{c|c} A & \mathbf{x}_2 \\ \hline \end{array} \right] = \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix}$$

$$\left[\begin{array}{c|c} A & \mathbf{x}_n \\ \hline \end{array} \right] = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$$



Homogeneous System

$$\begin{array}{ccccccccccc} a_{11} & x_1 & + & a_{12} & x_2 & + & \cdots & + & a_{1n} & x_n & = & 0 \\ a_{21} & x_1 & + & a_{22} & x_2 & + & \cdots & + & a_{2n} & x_n & = & 0 \\ \vdots & & & \vdots & & & & & \vdots & & & \vdots \\ a_{m1} & x_1 & + & a_{m2} & x_2 & + & \cdots & + & a_{mn} & x_n & = & 0 \end{array}$$

All constant terms are zero

Homogeneous System

All constant terms
are zero

$$\begin{matrix} & & i & j \\ i & & | & | \\ j & & | & | \\ & & & \end{matrix} \left[\begin{array}{cc} & \\ \hline & \\ \hline & \\ \hline & \end{array} \right]$$

A 2x2 matrix with a diagonal line from top-left to bottom-right. The top-left element is 0 (blue), the top-right element is 1 (red), the bottom-left element is 1 (red), and the bottom-right element is 0 (blue). The columns are labeled *i* and *j* at the top, and the rows are labeled *i* and *j* on the left. The 0s are highlighted with light blue boxes, and the 1s are highlighted with light red boxes.

$$\begin{matrix} & & i \\ i & & | \\ & & \end{matrix} \left[\begin{array}{c} \\ \hline \\ \hline \end{array} \right]$$

A 1x1 matrix with a diagonal line from top-left to bottom-right. The single element is *c* (red). The column is labeled *i* at the top, and the row is labeled *i* on the left. The element *c* is highlighted with a light red box.

$$\begin{matrix} & & i & j \\ i & & | & | \\ j & & | & | \\ & & & \end{matrix} \left[\begin{array}{cc} & \\ \hline & \\ \hline & \\ \hline & \end{array} \right]$$

A 2x2 matrix with a diagonal line from top-left to bottom-right. The bottom-left element is *c* (red). The columns are labeled *i* and *j* at the top, and the rows are labeled *i* and *j* on the left. The element *c* is highlighted with a light red box.

References

- [1] <http://en.wikipedia.org/>
- [2] Anton & Busby, "Contemporary Linear Algebra"