

## Determinants

---

- Determinant of a square matrix  $A$  is denoted by  $|A|$  or  $\det(A)$ .
- Determinant of a matrix  $A = [a]_{1 \times 1}$  is  $|A| = |a| = a$

- Determinant of a matrix  $A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}$  is given by,  $|A| = \begin{vmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{vmatrix} = a_{11}a_{22} - a_{21}a_{12}$

- Determinant of a matrix  $A = \begin{bmatrix} a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \\ c_1 & c_2 & c_3 \end{bmatrix}$  is given by (expanding along  $R_1$ ):

$$\begin{aligned} A = \begin{bmatrix} a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \\ c_1 & c_2 & c_3 \end{bmatrix} &= (-1)^{1+1} a_1 \begin{vmatrix} b_2 & b_3 \\ c_2 & c_3 \end{vmatrix} + (-1)^{1+2} a_2 \begin{vmatrix} b_1 & b_3 \\ c_1 & c_3 \end{vmatrix} + (-1)^{1+3} a_3 \begin{vmatrix} b_1 & b_2 \\ c_1 & c_2 \end{vmatrix} \\ &= a_1 \begin{vmatrix} b_2 & b_3 \\ c_2 & c_3 \end{vmatrix} - a_2 \begin{vmatrix} b_1 & b_3 \\ c_1 & c_3 \end{vmatrix} + a_3 \begin{vmatrix} b_1 & b_2 \\ c_1 & c_2 \end{vmatrix} \end{aligned}$$

Similarly, we can find the determinant of  $A$  by expanding along any other row or along any column.

- The various properties of determinants are as follows:
  - If the rows and the columns of a square matrix are interchanged, then the value of the determinant remains unchanged.

**Example:**

$$|A| = \begin{vmatrix} a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \\ c_1 & c_2 & c_3 \end{vmatrix} = \begin{vmatrix} a_1 & b_1 & c_1 \\ a_2 & b_2 & c_2 \\ a_3 & b_3 & c_3 \end{vmatrix}$$

This property is same as saying, if  $A$  is a square matrix, then  $|A| = |A'|$

- If we interchange any two rows (or columns), then sign of determinant changes.

**Example:**

$$\begin{vmatrix} a_1 & b_1 & c_1 \\ a_2 & b_2 & c_2 \\ a_3 & b_3 & c_3 \end{vmatrix} = - \begin{vmatrix} b_1 & a_1 & c_1 \\ b_2 & a_2 & c_2 \\ b_3 & a_3 & c_3 \end{vmatrix}, \text{ by applying } C_1 \leftrightarrow C_2$$

$$= \begin{vmatrix} b_3 & a_3 & c_3 \\ b_2 & a_2 & c_2 \\ b_1 & a_1 & c_1 \end{vmatrix}, \text{ by applying } R_1 \leftrightarrow R_3$$

- If any two rows or any two columns of a determinant are identical or proportional, then the value of the determinant is zero.

**Example:**

$$\begin{vmatrix} a_1 & b_1 & c_1 \\ a_2 & b_2 & c_2 \\ ka_1 & kb_1 & kc_1 \end{vmatrix} = 0, \text{ where } k \text{ is a constant}$$

- If each element of a row or a column of determinant is multiplied by a constant  $a$ , then its determinant value gets multiplied by  $a$ .

**Example:** Area of a triangle with vertices  $(x_1, y_1)$ ,  $(x_2, y_2)$ , and  $(x_3, y_3)$  is given by,

$$\Delta = \frac{1}{2} \begin{vmatrix} x_1 & y_1 & 1 \\ x_2 & y_2 & 1 \\ x_3 & y_3 & 1 \end{vmatrix}$$

Since area is always positive, we take the absolute value of the above determinant.

- If  $A$  is a square matrix, then  $A (\text{adj } A) = (\text{adj } A) A = |A| I$
- A square matrix  $A$  is said to be singular, if  $|A| = 0$
- A square matrix  $A$  is said to be non-singular, if  $|A| \neq 0$
- If  $A$  and  $B$  are square matrices of same order, then  $|AB| = |A||B|$

Therefore, if  $A$  and  $B$  are non-singular matrices of same order, then  $AB$  and  $BA$  are also non-singular matrices of same order.

- If  $A$  is a non-singular matrix of order  $n$ , then  $|\text{adj } A| = |A|^{n-1}$
- A square matrix  $A$  is invertible, if and only if  $A$  is non-singular and inverse of  $A$  is given by the formula:

$$A^{-1} = \frac{1}{|A|} (\text{adj } A)$$

- If  $A$  is a square matrix, then  $A (\text{adj}A) = (\text{adj}A) A = |A| I$
- A square matrix  $A$  is said to be singular, if  $|A| \neq 0$
- A square matrix  $A$  is said to be non-singular, if  $|A| \neq 0$
- If  $A$  and  $B$  are square matrices of same order, then  $|AB| = |A||B|$

Therefore, if  $A$  and  $B$  are non-singular matrices of same order, then  $AB$  and  $BA$  are also non-singular matrices of same order.

- If  $A$  is a non-singular matrix of order  $n$ , then  $(\text{adj}A)(\text{adj}A) = |A|^{n-1}$
- A square matrix  $A$  is invertible, if and only if  $A$  is non-singular and inverse of  $A$  is given by the formula:

$$A^{-1} = \frac{1}{|A|} (\text{adj}A)$$

$$\begin{aligned} a_1x + b_1y + c_1z &= d_1 \\ a_2x + b_2y + c_2z &= d_2 \end{aligned}$$

- The system of following linear equations  $a_3x + b_3y + c_3z = d_3$  can be written as  $AX = B$ , where

$$A = \begin{bmatrix} a_1 & b_1 & c_1 \\ a_2 & b_2 & c_2 \\ a_3 & b_3 & c_3 \end{bmatrix}, X = \begin{bmatrix} x \\ y \\ z \end{bmatrix}, B = \begin{bmatrix} d_1 \\ d_2 \\ d_3 \end{bmatrix}$$

- A system of linear equations is said to be consistent, if its solution (one or more) exists.
- A system of linear equations is said to be inconsistent, if its solution does not exist.
- Unique solution of the equation  $AX = B$  is given by  $X = A^{-1} B$ , where  $|A| \neq 0$
- For a square matrix  $A$  in equation  $AX = B$ , if
  - $|A| \neq 0$ , then there exists a unique solution
  - $|A| \neq 0$  and  $(\text{adj}A) B \neq O$ , then no solution exists
  - $|A| \neq 0$  and  $(\text{adj}A) B = O$ , then the system may or may not be consistent

**Example 2:** Solve the following system of linear equations:

$$\begin{aligned} x - 3y + 4z &= 12 \\ 2x + 2y - 3z &= -7 \\ 6x - y + 2z &= 13 \end{aligned}$$

**Solution:** The given system of equations can be written in the form  $AX = B$ , where

$$A = \begin{bmatrix} 1 & -3 & 4 \\ 2 & 2 & -3 \\ 6 & -1 & 2 \end{bmatrix}, X = \begin{bmatrix} x \\ y \\ z \end{bmatrix} \text{ and } B = \begin{bmatrix} 12 \\ -7 \\ 13 \end{bmatrix}$$

$$\text{Now, } |A| = 1[2 \times 2 - (-1)(-3)] + 3[2 \times 2 - 6(-3)] + 4[2 \times (-1) - 6 \times 2] = 11 \neq 0$$

Therefore,  $A$  is a non-singular matrix and hence, the given system of linear equations has only one solution.

Now,

$$A_{11} = [2 \times 2 - (-1)(-3)] = 1$$

$$A_{12} = -[2 \times 2 - 6(-3)] = -22$$

$$A_{13} = [2(-1) - 6 \times 2] = -14$$

$$A_{21} = -[(-3) \times 2 - (-1) \times 4] = 2$$

$$A_{22} = [1 \times 2 - 6 \times 4] = -22$$

$$A_{23} = -[1(-1) - 6(-3)] = -17$$

$$A_{31} = [(-3)(-3) - 4 \times 2] = 1$$

$$A_{32} = -[1(-3) - 2 \times 4] = 11$$

$$A_{33} = [1 \times 2 - 2(-3)] = 8$$

$$\therefore A^{-1} = \frac{1}{|A|} (\text{adj } A) = \frac{1}{11} \begin{bmatrix} 1 & 2 & 1 \\ -22 & -22 & 11 \\ -14 & -17 & 8 \end{bmatrix}$$

$$\text{Now, } X = A^{-1}B$$

$$\Rightarrow \begin{bmatrix} x \\ y \\ z \end{bmatrix} = \frac{1}{11} \begin{bmatrix} 1 & 2 & 1 \\ -22 & -22 & 11 \\ -14 & -17 & 8 \end{bmatrix} \begin{bmatrix} 12 \\ -7 \\ 13 \end{bmatrix} = \frac{1}{11} \begin{bmatrix} 11 \\ 33 \\ 55 \end{bmatrix} = \begin{bmatrix} 1 \\ 3 \\ 5 \end{bmatrix}$$

$$x = 1, y = 3, \text{ and } z = 5$$