

# Matrix Introduction

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# Matrices - Introduction

Matrix algebra has at least two advantages:

- Reduces complicated systems of equations to simple expressions
- Adaptable to systematic method of mathematical treatment and well suited to computers

## **Definition:**

**A matrix is a set or group of numbers arranged in a square or rectangular array enclosed by two brackets**

$$\begin{bmatrix} 1 & -1 \end{bmatrix} \quad \begin{bmatrix} 4 & 2 \\ -3 & 0 \end{bmatrix} \quad \begin{bmatrix} a & b \\ c & d \end{bmatrix}$$

# Matrices - Introduction

## Properties:

- **A specified number of rows and a specified number of columns**
- **Two numbers (rows x columns) describe the dimensions or size of the matrix.**

## Examples:

3x3 matrix	$\begin{bmatrix} 1 & 2 & 4 \\ 4 & -1 & 5 \\ 3 & 3 & 3 \end{bmatrix}$	$\begin{bmatrix} 1 & 1 & 3 & -3 \\ 0 & 0 & 3 & 2 \end{bmatrix}$	$\begin{bmatrix} 1 & -1 \end{bmatrix}$
2x4 matrix			
1x2 matrix			

# Matrices - Introduction

A matrix is denoted by a bold capital letter and the elements within the matrix are denoted by lower case letters

e.g. matrix  $[A]$  with elements  $a_{ij}$

$$\mathbf{A}_{m \times n} = \begin{bmatrix} a_{11} & a_{12} \cdots & a_{ij} & a_{in} \\ a_{21} & a_{22} \cdots & a_{ij} & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{m1} & a_{m2} & a_{ij} & a_{mn} \end{bmatrix}$$

$i$  goes from 1 to  $m$

$j$  goes from 1 to  $n$

# Matrices - Introduction

## TYPES OF MATRICES

### 1. Column matrix or vector:

The number of rows may be any integer but the number of columns is always 1

$$\begin{bmatrix} 1 \\ 4 \\ 2 \end{bmatrix}$$

$$\begin{bmatrix} 1 \\ -3 \end{bmatrix}$$

$$\begin{bmatrix} a_{11} \\ a_{21} \\ \vdots \\ a_{m1} \end{bmatrix}$$

# Matrices - Introduction

## TYPES OF MATRICES

### 2. Row matrix or vector

Any number of columns but only one row

$$\begin{bmatrix} 1 & 1 & 6 \end{bmatrix}$$

$$\begin{bmatrix} 0 & 3 & 5 & 2 \end{bmatrix}$$

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} & \cdots & a_{1n} \end{bmatrix}$$

# Matrices - Introduction

## TYPES OF MATRICES

### 3. Rectangular matrix

Contains more than one element and number of rows is not equal to the number of columns

$$\begin{bmatrix} 1 & 1 \\ 3 & 7 \\ 7 & -7 \\ 7 & 6 \end{bmatrix}$$

$$\begin{bmatrix} 1 & 1 & 1 & 0 & 0 \\ 2 & 0 & 3 & 3 & 0 \end{bmatrix}$$

$$m \neq n$$

# Matrices - Introduction

## TYPES OF MATRICES

### 4. Square matrix

The number of rows is equal to the number of columns

(a square matrix  $\mathbf{A}$  has an order of  $m$ )  
 $m \times m$

$$\begin{bmatrix} 1 & 1 \\ 3 & 0 \end{bmatrix} \quad \begin{bmatrix} 1 & 1 & 1 \\ 9 & 9 & 0 \\ 6 & 6 & 1 \end{bmatrix}$$

The principal or main diagonal of a square matrix is composed of all elements  $a_{ij}$  for which  $i=j$



# Matrices - Introduction

## TYPES OF MATRICES

### 5. Diagonal matrix

A square matrix where all the elements are zero except those on the main diagonal

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 2 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$\begin{bmatrix} 3 & 0 & 0 & 0 \\ 0 & 3 & 0 & 0 \\ 0 & 0 & 5 & 0 \\ 0 & 0 & 0 & 9 \end{bmatrix}$$

i.e.  $a_{ij} = 0$  for all  $i \neq j$

$a_{ij} \neq 0$  for some or all  $i = j$

# Matrices - Introduction

## TYPES OF MATRICES

### 6. Unit or Identity matrix - I

A diagonal matrix with ones on the main diagonal

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

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

$$\begin{bmatrix} a_{ij} & 0 \\ 0 & a_{ij} \end{bmatrix}$$

i.e.  $a_{ij} = 0$  for all  $i \neq j$

$a_{ij} = 1$  for some or all  $i = j$

# Matrices - Introduction

## TYPES OF MATRICES

### 7. Null (zero) matrix - 0

All elements in the matrix are zero

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

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

$$a_{ij} = 0 \quad \text{For all } i, j$$

# Matrices - Introduction

## TYPES OF MATRICES

### 8. Triangular matrix

A square matrix whose elements above or below the main diagonal are all zero

$$\begin{bmatrix} 1 & 0 & 0 \\ 2 & 1 & 0 \\ 5 & 2 & 3 \end{bmatrix}$$

$$\begin{bmatrix} 1 & 0 & 0 \\ 2 & 1 & 0 \\ 5 & 2 & 3 \end{bmatrix}$$

$$\begin{bmatrix} 1 & 8 & 9 \\ 0 & 1 & 6 \\ 0 & 0 & 3 \end{bmatrix}$$

# Matrices - Introduction

## TYPES OF MATRICES

### 8a. Upper triangular matrix

A square matrix whose elements below the main diagonal are all zero

$$\begin{bmatrix} a_{ij} & a_{ij} & a_{ij} \\ 0 & a_{ij} & a_{ij} \\ 0 & 0 & a_{ij} \end{bmatrix}$$

$$\begin{bmatrix} 1 & 8 & 7 \\ 0 & 1 & 8 \\ 0 & 0 & 3 \end{bmatrix}$$

$$\begin{bmatrix} 1 & 7 & 4 & 4 \\ 0 & 1 & 7 & 4 \\ 0 & 0 & 7 & 8 \\ 0 & 0 & 0 & 3 \end{bmatrix}$$

i.e.  $a_{ij} = 0$  for all  $i > j$

# Matrices - Introduction

## TYPES OF MATRICES

### 8b. Lower triangular matrix

A square matrix whose elements above the main diagonal are all zero

$$\begin{bmatrix} a_{ij} & 0 & 0 \\ a_{ij} & a_{ij} & 0 \\ a_{ij} & a_{ij} & a_{ij} \end{bmatrix}$$

$$\begin{bmatrix} 1 & 0 & 0 \\ 2 & 1 & 0 \\ 5 & 2 & 3 \end{bmatrix}$$

i.e.  $a_{ij} = 0$  for all  $i < j$

# Matrices – Introduction

## TYPES OF MATRICES

### 9. Scalar matrix

A diagonal matrix whose main diagonal elements are equal to the same scalar

A scalar is defined as a single number or constant

$$\begin{bmatrix} a_{ij} & 0 & 0 \\ 0 & a_{ij} & 0 \\ 0 & 0 & a_{ij} \end{bmatrix} \quad \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad \begin{bmatrix} 6 & 0 & 0 & 0 \\ 0 & 6 & 0 & 0 \\ 0 & 0 & 6 & 0 \\ 0 & 0 & 0 & 6 \end{bmatrix}$$

i.e.  $a_{ij} = 0$  for all  $i \neq j$   
 $a_{ij} = a$  for all  $i = j$



# Matrices

▀ Matrix Operations



# Matrices - Operations

## EQUALITY OF MATRICES

Two matrices are said to be equal only when all corresponding elements are equal

Therefore their size or dimensions are equal as well

$$\mathbf{A} = \begin{bmatrix} 1 & 0 & 0 \\ 2 & 1 & 0 \\ 5 & 2 & 3 \end{bmatrix} \quad \mathbf{B} = \begin{bmatrix} 1 & 0 & 0 \\ 2 & 1 & 0 \\ 5 & 2 & 3 \end{bmatrix} \quad \mathbf{A} = \mathbf{B}$$

# Matrices - Operations

Some properties of equality:

- If  $\mathbf{A} = \mathbf{B}$ , then  $\mathbf{B} = \mathbf{A}$  for all  $\mathbf{A}$  and  $\mathbf{B}$
- If  $\mathbf{A} = \mathbf{B}$ , and  $\mathbf{B} = \mathbf{C}$ , then  $\mathbf{A} = \mathbf{C}$  for all  $\mathbf{A}$ ,  $\mathbf{B}$  and  $\mathbf{C}$

$$\mathbf{A} = \begin{bmatrix} 1 & 0 & 0 \\ 2 & 1 & 0 \\ 5 & 2 & 3 \end{bmatrix} \quad \mathbf{B} = \begin{bmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{bmatrix}$$

$$\text{If } \mathbf{A} = \mathbf{B} \text{ then } a_{ij} = b_{ij}$$

# Matrices - Operations

## ADDITION AND SUBTRACTION OF MATRICES

The sum or difference of two matrices, **A** and **B** of the same size yields a matrix **C** of the same size

$$c_{ij} = a_{ij} + b_{ij}$$

Matrices of different sizes cannot be added or subtracted

# Matrices - Operations

Commutative Law:

$$\mathbf{A} + \mathbf{B} = \mathbf{B} + \mathbf{A}$$

Associative Law:

$$\mathbf{A} + (\mathbf{B} + \mathbf{C}) = (\mathbf{A} + \mathbf{B}) + \mathbf{C} = \mathbf{A} + \mathbf{B} + \mathbf{C}$$

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

**A**  
2x3

**B**  
2x3

**C**  
2x3

# Matrices - Operations

$$\mathbf{A} + \mathbf{0} = \mathbf{0} + \mathbf{A} = \mathbf{A}$$

$$\mathbf{A} + (-\mathbf{A}) = \mathbf{0} \text{ (where } -\mathbf{A} \text{ is the matrix composed of } -a_{ij} \text{ as elements)}$$

$$\begin{bmatrix} 6 & 4 & 2 \\ 3 & 2 & 7 \end{bmatrix} - \begin{bmatrix} 1 & 2 & 0 \\ 1 & 0 & 8 \end{bmatrix} = \begin{bmatrix} 5 & 2 & 2 \\ 2 & 2 & -1 \end{bmatrix}$$

# Matrices - Operations

## SCALAR MULTIPLICATION OF MATRICES

Matrices can be multiplied by a scalar (constant or single element)

Let  $k$  be a scalar quantity; then

$$\mathbf{kA} = \mathbf{Ak}$$

Ex. If  $k=4$  and

$$A = \begin{bmatrix} 3 & -1 \\ 2 & 1 \\ 2 & -3 \\ 4 & 1 \end{bmatrix}$$

# Matrices - Operations

$$4 \times \begin{bmatrix} 3 & -1 \\ 2 & 1 \\ 2 & -3 \\ 4 & 1 \end{bmatrix} = \begin{bmatrix} 3 & -1 \\ 2 & 1 \\ 2 & -3 \\ 4 & 1 \end{bmatrix} \times 4 = \begin{bmatrix} 12 & -4 \\ 8 & 4 \\ 8 & -12 \\ 16 & 4 \end{bmatrix}$$

Properties:

- $k(\mathbf{A} + \mathbf{B}) = k\mathbf{A} + k\mathbf{B}$
- $(k + g)\mathbf{A} = k\mathbf{A} + g\mathbf{A}$
- $k(\mathbf{AB}) = (k\mathbf{A})\mathbf{B} = \mathbf{A}(k\mathbf{B})$
- $k(g\mathbf{A}) = (kg)\mathbf{A}$

# Matrices - Operations

## MULTIPLICATION OF MATRICES

The product of two matrices is another matrix

Two matrices **A** and **B** must be **conformable** for multiplication to be possible


i.e. the number of columns of **A** must equal the number of rows of **B**

Example.

$$\begin{array}{ccccc} \mathbf{A} & \times & \mathbf{B} & = & \mathbf{C} \\ (1 \times 3) & & (3 \times 1) & & (1 \times 1) \end{array}$$



# Matrices - Operations




$$\begin{matrix} \mathbf{B} & \times & \mathbf{A} & = & \text{Not possible!} \\ (2 \times 1) & & (4 \times 2) \end{matrix}$$

$$\begin{matrix} \mathbf{A} & \times & \mathbf{B} & = & \text{Not possible!} \\ (6 \times 2) & & (6 \times 3) \end{matrix}$$

Example

$$\begin{matrix} \mathbf{A} & \times & \mathbf{B} & = & \mathbf{C} \\ (2 \times 3) & & (3 \times 2) & & (2 \times 2) \end{matrix}$$

# Matrices - Operations


$$\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \end{bmatrix} \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \\ b_{31} & b_{32} \end{bmatrix} = \begin{bmatrix} c_{11} & c_{12} \\ c_{21} & c_{22} \end{bmatrix}$$

$$(a_{11} \times b_{11}) + (a_{12} \times b_{21}) + (a_{13} \times b_{31}) = c_{11}$$



$$(a_{11} \times b_{12}) + (a_{12} \times b_{22}) + (a_{13} \times b_{32}) = c_{12}$$

$$(a_{21} \times b_{11}) + (a_{22} \times b_{21}) + (a_{23} \times b_{31}) = c_{21}$$

$$(a_{21} \times b_{12}) + (a_{22} \times b_{22}) + (a_{23} \times b_{32}) = c_{22}$$

Successive multiplication of row  $i$  of  $\mathbf{A}$  with column  $j$  of  $\mathbf{B}$  – row by column multiplication

# Matrices - Operations


$$\begin{bmatrix} 1 & 2 & 3 \\ 4 & 2 & 7 \end{bmatrix} \begin{bmatrix} 4 & 8 \\ 6 & 2 \\ 5 & 3 \end{bmatrix} = \begin{bmatrix} (1 \times 4) + (2 \times 6) + (3 \times 5) & (1 \times 8) + (2 \times 2) + (3 \times 3) \\ (4 \times 4) + (2 \times 6) + (7 \times 5) & (4 \times 8) + (2 \times 2) + (7 \times 3) \end{bmatrix}$$
$$= \begin{bmatrix} 31 & 21 \\ 63 & 57 \end{bmatrix}$$

Remember also:

$$\mathbf{IA} = \mathbf{A}$$

$$\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 31 & 21 \\ 63 & 57 \end{bmatrix} = \begin{bmatrix} 31 & 21 \\ 63 & 57 \end{bmatrix}$$

# Matrices - Operations

Assuming that matrices **A**, **B** and **C** are conformable for the operations indicated, the following are true:

1.  $\mathbf{AI} = \mathbf{IA} = \mathbf{A}$
2.  $\mathbf{A(BC)} = (\mathbf{AB})\mathbf{C} = \mathbf{ABC}$  - (associative law)
3.  $\mathbf{A(B+C)} = \mathbf{AB} + \mathbf{AC}$  - (first distributive law)
4.  $(\mathbf{A+B})\mathbf{C} = \mathbf{AC} + \mathbf{BC}$  - (second distributive law)

## Caution!

1.  $\mathbf{AB}$  not generally equal to  $\mathbf{BA}$ ,  $\mathbf{BA}$  may not be conformable
2. If  $\mathbf{AB} = \mathbf{0}$ , neither  $\mathbf{A}$  nor  $\mathbf{B}$  necessarily  $= \mathbf{0}$
3. If  $\mathbf{AB} = \mathbf{AC}$ ,  $\mathbf{B}$  not necessarily  $= \mathbf{C}$

# Matrices - Operations

**AB** not generally equal to **BA**, **BA** may not be conformable

$$T = \begin{bmatrix} 1 & 2 \\ 5 & 0 \end{bmatrix}$$

$$S = \begin{bmatrix} 3 & 4 \\ 0 & 2 \end{bmatrix}$$

$$TS = \begin{bmatrix} 1 & 2 \\ 5 & 0 \end{bmatrix} \begin{bmatrix} 3 & 4 \\ 0 & 2 \end{bmatrix} = \begin{bmatrix} 3 & 8 \\ 15 & 20 \end{bmatrix}$$

$$ST = \begin{bmatrix} 3 & 4 \\ 0 & 2 \end{bmatrix} \begin{bmatrix} 1 & 2 \\ 5 & 0 \end{bmatrix} = \begin{bmatrix} 23 & 6 \\ 10 & 0 \end{bmatrix}$$

# Matrices - Operations

If  $\mathbf{AB} = \mathbf{0}$ , neither  $\mathbf{A}$  nor  $\mathbf{B}$  necessarily  $= \mathbf{0}$

$$\begin{bmatrix} 1 & 1 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} 2 & 3 \\ -2 & -3 \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix}$$

# Matrices - Operations

## TRANSPOSE OF A MATRIX

If :

$$A = \begin{bmatrix} 2 & 4 & 7 \\ 5 & 3 & 1 \end{bmatrix}$$

Then transpose of A, denoted  $A^T$  is:

$$A^T = \begin{bmatrix} 2 & 5 \\ 4 & 3 \\ 7 & 1 \end{bmatrix}$$

$$a_{ij} = a_{ji}^T \quad \text{For all } i \text{ and } j$$

# Matrices - Operations

To transpose:

Interchange rows and columns

The dimensions of  $\mathbf{A}^T$  are the reverse of the dimensions of  $\mathbf{A}$

$$\mathbf{A} = {}_2\mathbf{A}^3 = \begin{bmatrix} 2 & 4 & 7 \\ 5 & 3 & 1 \end{bmatrix} \quad 2 \times 3$$

$$\mathbf{A}^T = {}_3\mathbf{A}^{T^2} = \begin{bmatrix} 2 & 5 \\ 4 & 3 \\ 7 & 1 \end{bmatrix} \quad 3 \times 2$$



# Matrices - Operations

Properties of transposed matrices:

1.  $(\mathbf{A} + \mathbf{B})^T = \mathbf{A}^T + \mathbf{B}^T$
2.  $(\mathbf{AB})^T = \mathbf{B}^T \mathbf{A}^T$
3.  $(k\mathbf{A})^T = k\mathbf{A}^T$
4.  $(\mathbf{A}^T)^T = \mathbf{A}$

# Matrices - Operations

1.  $(\mathbf{A}+\mathbf{B})^T = \mathbf{A}^T + \mathbf{B}^T$

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

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

# Matrices - Operations

$$(\mathbf{AB})^T = \mathbf{B}^T \mathbf{A}^T$$

$$\begin{bmatrix} 1 & 1 & 0 \\ 0 & 2 & 3 \end{bmatrix} \begin{bmatrix} 1 \\ 1 \\ 2 \end{bmatrix} = \begin{bmatrix} 2 \\ 8 \end{bmatrix} \Rightarrow [2 \quad 8]$$

$$[1 \quad 1 \quad 2] \begin{bmatrix} 1 & 0 \\ 1 & 2 \\ 0 & 3 \end{bmatrix} = [2 \quad 8]$$

# Matrices - Operations

## SYMMETRIC MATRICES

A Square matrix is symmetric if it is equal to its transpose:

$$\mathbf{A} = \mathbf{A}^T$$

$$A = \begin{bmatrix} a & b \\ b & d \end{bmatrix}$$

$$A^T = \begin{bmatrix} a & b \\ b & d \end{bmatrix}$$

# Matrices - Operations

When the original matrix is square, transposition does not affect the elements of the main diagonal

$$A = \begin{bmatrix} a & b \\ c & d \end{bmatrix}$$
$$A^T = \begin{bmatrix} a & c \\ b & d \end{bmatrix}$$

The identity matrix, **I**, a diagonal matrix **D**, and a scalar matrix, **K**, are equal to their transpose since the diagonal is unaffected.

# Matrices - Operations

## INVERSE OF A MATRIX

Consider a scalar  $k$ . The inverse is the reciprocal or division of 1 by the scalar.

Example:

$k=7$  the inverse of  $k$  or  $k^{-1} = 1/k = 1/7$

Division of matrices is not defined since there may be  $\mathbf{AB} = \mathbf{AC}$  while  $\mathbf{B} \neq \mathbf{C}$

Instead matrix inversion is used.

The inverse of a square matrix,  $\mathbf{A}$ , if it exists, is the unique matrix  $\mathbf{A}^{-1}$  where:

$$\mathbf{AA}^{-1} = \mathbf{A}^{-1} \mathbf{A} = \mathbf{I}$$

# Matrices - Operations

Example:

$$A = \begin{bmatrix} 3 & 1 \\ 2 & 1 \end{bmatrix}$$

$$A^{-1} = \begin{bmatrix} 1 & -1 \\ -2 & 3 \end{bmatrix}$$

Because:

$$\begin{bmatrix} 1 & -1 \\ -2 & 3 \end{bmatrix} \begin{bmatrix} 3 & 1 \\ 2 & 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

$$\begin{bmatrix} 3 & 1 \\ 2 & 1 \end{bmatrix} \begin{bmatrix} 1 & -1 \\ -2 & 3 \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

# Matrices - Operations

Properties of the inverse:

$$(AB)^{-1} = B^{-1}A^{-1}$$

$$(A^{-1})^{-1} = A$$

$$(A^T)^{-1} = (A^{-1})^T$$

$$(kA)^{-1} = \frac{1}{k} A^{-1}$$

A square matrix that has an inverse is called a nonsingular matrix

A matrix that does not have an inverse is called a singular matrix

Square matrices have inverses except when the determinant is zero

When the determinant of a matrix is zero the matrix is singular



# Matrices - Operations

## DETERMINANT OF A MATRIX

To compute the inverse of a matrix, the determinant is required

Each square matrix  $\mathbf{A}$  has a unit scalar value called the determinant of  $\mathbf{A}$ , denoted by  $\det \mathbf{A}$  or  $|\mathbf{A}|$

If  $A = \begin{bmatrix} 1 & 2 \\ 6 & 5 \end{bmatrix}$

then  $|A| = \begin{vmatrix} 1 & 2 \\ 6 & 5 \end{vmatrix}$

# Matrices - Operations

If  $\mathbf{A} = [\mathbf{A}]$  is a single element (1x1), then the determinant is defined as the value of the element

Then  $|\mathbf{A}| = \det \mathbf{A} = a_{11}$

If  $\mathbf{A}$  is (n x n), its determinant may be defined in terms of order (n-1) or less.

# Matrices - Operations

## MINORS

If  $\mathbf{A}$  is an  $n \times n$  matrix and one row and one column are deleted, the resulting matrix is an  $(n-1) \times (n-1)$  submatrix of  $\mathbf{A}$ .

The determinant of such a submatrix is called a minor of  $\mathbf{A}$  and is designated by  $m_{ij}$ , where  $i$  and  $j$  correspond to the deleted row and column, respectively.

$m_{ij}$  is the minor of the element  $a_{ij}$  in  $\mathbf{A}$ .

# Matrices - Operations

eg.

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix}$$

Each element in  $\mathbf{A}$  has a minor

Delete first row and column from  $\mathbf{A}$  .

**The determinant of the remaining 2 x 2 submatrix is the minor of  $a_{11}$**

$$m_{11} = \begin{vmatrix} a_{22} & a_{23} \\ a_{32} & a_{33} \end{vmatrix}$$

# Matrices - Operations

Therefore the minor of  $a_{12}$  is:

$$m_{12} = \begin{vmatrix} a_{21} & a_{23} \\ a_{31} & a_{33} \end{vmatrix}$$

And the minor for  $a_{13}$  is:

$$m_{13} = \begin{vmatrix} a_{21} & a_{22} \\ a_{31} & a_{32} \end{vmatrix}$$

# Matrices - Operations

## COFACTORS

The cofactor  $C_{ij}$  of an element  $a_{ij}$  is defined as:

$$C_{ij} = (-1)^{i+j} m_{ij}$$

When the sum of a row number  $i$  and column  $j$  is even,  $c_{ij} = m_{ij}$  and when  $i+j$  is odd,  $c_{ij} = -m_{ij}$

$$c_{11}(i=1, j=1) = (-1)^{1+1} m_{11} = +m_{11}$$

$$c_{12}(i=1, j=2) = (-1)^{1+2} m_{12} = -m_{12}$$

$$c_{13}(i=1, j=3) = (-1)^{1+3} m_{13} = +m_{13}$$

# Matrices - Operations

## DETERMINANTS CONTINUED

The determinant of an  $n \times n$  matrix  $\mathbf{A}$  can now be defined as

$$|\mathbf{A}| = \det \mathbf{A} = a_{11}c_{11} + a_{12}c_{12} + \dots + a_{1n}c_{1n}$$

The determinant of  $\mathbf{A}$  is therefore the sum of the products of the elements of the first row of  $\mathbf{A}$  and their corresponding cofactors.

(It is possible to define  $|\mathbf{A}|$  in terms of any other row or column but for simplicity, the first row only is used)

# Matrices - Operations

Therefore the 2 x 2 matrix :

$$A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}$$

Has cofactors :

$$c_{11} = m_{11} = |a_{22}| = a_{22}$$

And:

$$c_{12} = -m_{12} = -|a_{21}| = -a_{21}$$

And the determinant of  $\mathbf{A}$  is:

$$|A| = a_{11}c_{11} + a_{12}c_{12} = a_{11}a_{22} - a_{12}a_{21}$$



# Matrices - Operations

Example 1:

$$A = \begin{bmatrix} 3 & 1 \\ 1 & 2 \end{bmatrix}$$

$$|A| = (3)(2) - (1)(1) = 5$$

# Matrices - Operations

For a 3 x 3 matrix:

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix}$$

The cofactors of the first row are:

$$c_{11} = \begin{vmatrix} a_{22} & a_{23} \\ a_{32} & a_{33} \end{vmatrix} = a_{22}a_{33} - a_{23}a_{32}$$

$$c_{12} = -\begin{vmatrix} a_{21} & a_{23} \\ a_{31} & a_{33} \end{vmatrix} = -(a_{21}a_{33} - a_{23}a_{31})$$

$$c_{13} = \begin{vmatrix} a_{21} & a_{22} \\ a_{31} & a_{32} \end{vmatrix} = a_{21}a_{32} - a_{22}a_{31}$$

# Matrices - Operations

The determinant of a matrix A is:

$$|A| = a_{11}c_{11} + a_{12}c_{12} = a_{11}a_{22} - a_{12}a_{21}$$

Which by substituting for the cofactors in this case is:

$$|A| = a_{11}(a_{22}a_{33} - a_{23}a_{32}) - a_{12}(a_{21}a_{33} - a_{23}a_{31}) + a_{13}(a_{21}a_{32} - a_{22}a_{31})$$

# Matrices - Operations

Example 2:

$$A = \begin{bmatrix} 1 & 0 & 1 \\ 0 & 2 & 3 \\ -1 & 0 & 1 \end{bmatrix}$$

$$|A| = a_{11}(a_{22}a_{33} - a_{23}a_{32}) - a_{12}(a_{21}a_{33} - a_{23}a_{31}) + a_{13}(a_{21}a_{32} - a_{22}a_{31})$$

$$|A| = (1)(2 - 0) - (0)(0 + 3) + (1)(0 + 2) = 4$$