Objectives

- Formula for det A ($n!$ terms)
- Cofactor formula
- Tridiagonal matrices

## Formula for the determinant

We know that the determinant has the following three properties:

1. $\det I = 1$
2. Exchanging rows reverses the sign of the determinant.
3. The determinant is linear in each row separately.

- Last class we listed seven consequences of these properties.

$$\begin{vmatrix} a & b \\ c & d \end{vmatrix} = \begin{vmatrix} a & 0 \\ c & d \end{vmatrix} + \begin{vmatrix} 0 & b \\ c & d \end{vmatrix}$$

$$= \begin{vmatrix} a & 0 \\ c & 0 \end{vmatrix} + \begin{vmatrix} a & 0 \\ 0 & d \end{vmatrix} + \begin{vmatrix} 0 & b \\ c & 0 \end{vmatrix}$$

$$+\begin{vmatrix} 0 & b \\ 0 & d \end{vmatrix}$$

$$= 0 + ad + (-cd) + 0$$

$$= ad - bc$$

*<u>Note</u>: 3x3 can be found in notes lecture

$$\begin{vmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{vmatrix} = \begin{vmatrix} a_{11} & 0 & 0 \\ 0 & a_{21} & 0 \\ 0 & 0 & a_{31} \end{vmatrix}$$

$$+\begin{vmatrix} a_{11} & 0 & 0 \\ 0 & 0 & a_{23} \\ 0 & a_{32} & 0 \end{vmatrix}$$

$$\Rightarrow a_{11} a_{22} a_{33} - a_{11} a_{23} a_{32}$$

? 1 row exchange to get it back to I.

$$+\underbrace{\begin{vmatrix} 0 & a_{12} & 0 \\ a_{21} & 0 & 0 \\ 0 & 0 & a_{33} \end{vmatrix}}_{-a_{12}a_{21}a_{33}} +$$

$\Rightarrow$

$$\begin{aligned}
\begin{vmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{vmatrix} &= \begin{vmatrix} a_{11} & 0 & 0 \\ 0 & a_{22} & 0 \\ 0 & 0 & a_{33} \end{vmatrix} + \begin{vmatrix} a_{11} & 0 & 0 \\ 0 & 0 & a_{23} \\ 0 & a_{32} & 0 \end{vmatrix} + \begin{vmatrix} 0 & a_{12} & 0 \\ a_{21} & 0 & 0 \\ 0 & 0 & a_{33} \end{vmatrix} \\
&\quad + \begin{vmatrix} 0 & a_{12} & 0 \\ 0 & 0 & a_{23} \\ a_{31} & 0 & 0 \end{vmatrix} + \begin{vmatrix} 0 & 0 & a_{13} \\ a_{21} & 0 & 0 \\ 0 & a_{32} & 0 \end{vmatrix} + \begin{vmatrix} 0 & 0 & a_{13} \\ 0 & a_{22} & 0 \\ a_{31} & 0 & 0 \end{vmatrix} \\
&= a_{11}a_{22}a_{33} - a_{11}a_{23}a_{33} - a_{12}a_{21}a_{33} \\
&\quad + a_{12}a_{23}a_{31} + a_{13}a_{21}a_{32} - a_{13}a_{22}a_{31}.
\end{aligned}$$

## BIG Formula

$$\det A = \underbrace{\sum}_{n!\ \text{terms}^{*}} \pm\ a_{1\alpha}\, a_{2\beta}\, a_{3\gamma} \cdots a_{n\omega}$$

where $(\alpha, \beta, \gamma, \ldots, \omega)$ is some permutation of $(1, 2, 3, \ldots, n)$

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* Note: $n!$ is because there are $n$ ways to choose an element from the first row (ie a value of $\alpha$) after which there are only $n-1$ ways to choose an element from the second row that avoids a zero determinant.

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Example!

Compute det!

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

$(4,3,2,1) \to +1$ $\qquad$ 1 exchange: $(3,2,1,4) \to -1$

$\therefore$ det $= 0$

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## Cofactor Formula

The cofactor formula rewrites the big formula for the determinant of an $n \times n$ matrix in terms of the determinants of smaller matrices.

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(ex) $(3 \times 3)$

$$\det A = a_{11}(a_{22}a_{33} - a_{23}a_{32}) + a_{12}(-a_{21}a_{33} + a_{23}a_{31}) + a_{13}(a_{21}a_{32} - a_{22}a_{31})$$
$$= \begin{vmatrix} a_{11} & 0 & 0 \\ 0 & a_{22} & a_{23} \\ 0 & a_{32} & a_{33} \end{vmatrix} + \begin{vmatrix} 0 & a_{12} & 0 \\ a_{21} & 0 & a_{23} \\ a_{31} & 0 & a_{33} \end{vmatrix} + \begin{vmatrix} 0 & 0 & a_{13} \\ a_{21} & a_{22} & 0 \\ a_{31} & a_{32} & 0 \end{vmatrix}$$

Cofactor of $a_{ij} = C_{ij}$

$\pm \det \begin{pmatrix} n-1 \text{ matrix} \\ \text{with row } i \text{ erased} \\ \text{col } j \end{pmatrix}$

$+ \to i+j = \text{even}$

$- \to i+j = \text{odd}$

* Cofactor formula (along row 1)

$\det A = a_{11}C_{11} + a_{12}C_{12} + \dots + a_{1n}C_{1n}$

Applying this 2x2 matrix gives us:

$$\begin{vmatrix} a & b \\ c & d \end{vmatrix} = ad + b(-c)$$

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## Tridiagonal matrix

$$A_4 = \begin{bmatrix} 1 & 1 & 0 & 0 \\ 1 & 1 & 1 & 0 \\ 0 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 \end{bmatrix}.$$

What is the determinant of an $n \times n$ tridiagonal matrix of 1's?

$$|A_1| = 1, |A_2| = \begin{vmatrix} 1 & 1 \\ 1 & 1 \end{vmatrix} = 0, |A_3| = \begin{vmatrix} 1 & 1 & 0 \\ 1 & 1 & 1 \\ 0 & 1 & 1 \end{vmatrix} = -1$$

$$|A_4| = 1\begin{vmatrix} 1 & 1 & 0 \\ 1 & 1 & 1 \\ 0 & 1 & 1 \end{vmatrix} - 1\begin{vmatrix} 1 & 1 & 0 \\ 0 & 1 & 1 \\ 0 & 1 & 1 \end{vmatrix} = |A_3| - 1|A_2| = -1$$

In fact, $|A_n| = |A_{n-1}| - |A_{n-2}|$. We get a sequence which repeats every six terms:

$$|A_1| = 1, |A_2| = 0, |A_3| = -1, |A_4| = -1, |A_5| = 0, |A_6| = 1, |A_7| = 1.$$