4.4.30

AI25BTECH11034 - Sujal Chauhan

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Question

Show that four points $\mathbf{A}(4, 5, 1)$, $\mathbf{B}(0, -1, -1)$, $\mathbf{C}(3, 9, 4)$, $\mathbf{D}(-4, 4, 4)$ are coplanar.

Theory

If N points in $\mathbb{R}^3$ are given as

$$X_i = (x_i, y_i, z_i), \quad i = 1, 2, \dots, N,$$

then the condition for coplanarity is that the augmented matrix

$$A = \begin{pmatrix} x_1 & y_1 & z_1 & 1 \\ x_2 & y_2 & z_2 & 1 \\ \vdots & \vdots & \vdots & \vdots \\ x_N & y_N & z_N & 1 \end{pmatrix} \tag{1}$$

satisfies

$$\operatorname{rank}(A) \leq 3. \tag{2}$$

Solution

For the given four points to be coplanar, the rank of the following matrix must be less than 4:

$$\mathbf{A} = \begin{pmatrix} 4 & 5 & 1 & 1 \\ 0 & -1 & -1 & 1 \\ 3 & 9 & 4 & 1 \\ -4 & 4 & 4 & 1 \end{pmatrix} \tag{3}$$

$$\xrightarrow{R_3 \to R_3 - \frac{3}{4}R_1,\ R_4 \to R_4 + R_1} \begin{pmatrix} 4 & 5 & 1 & 1 \\ 0 & -1 & -1 & 1 \\ 0 & \frac{21}{4} & \frac{13}{4} & \frac{1}{4} \\ 0 & 9 & 5 & 2 \end{pmatrix} \tag{4}$$

Solution

$$\xrightarrow{R_1 \to \frac{1}{4} R_1} \begin{pmatrix} 1 & \frac{5}{4} & \frac{1}{4} & \frac{1}{4} \\ 0 & -1 & -1 & 1 \\ 0 & \frac{21}{4} & \frac{13}{4} & \frac{1}{4} \\ 0 & 9 & 5 & 2 \end{pmatrix} \tag{5}$$

$$\xrightarrow{R_2 \to -R_2} \begin{pmatrix} 1 & \frac{5}{4} & \frac{1}{4} & \frac{1}{4} \\ 0 & 1 & 1 & -1 \\ 0 & \frac{21}{4} & \frac{13}{4} & \frac{1}{4} \\ 0 & 9 & 5 & 2 \end{pmatrix} \tag{6}$$

$$\xrightarrow{R_3 \to R_3 - \frac{21}{4} R_2,\; R_4 \to R_4 - 9R_2} \begin{pmatrix} 1 & \frac{5}{4} & \frac{1}{4} & \frac{1}{4} \\ 0 & 1 & 1 & -1 \\ 0 & 0 & -2 & \frac{22}{4} \\ 0 & 0 & -4 & 11 \end{pmatrix} \tag{7}$$

Solution

$$\xrightarrow{R_3 \to -\frac{1}{2}R_3} \begin{pmatrix} 1 & \frac{5}{4} & \frac{1}{4} & \frac{1}{4} \\ 0 & 1 & 1 & -1 \\ 0 & 0 & 1 & -\frac{11}{4} \\ 0 & 0 & -4 & 11 \end{pmatrix} \tag{8}$$

$$\xrightarrow{R_4 \to R_4 + 4R_3} \begin{pmatrix} 1 & \frac{5}{4} & \frac{1}{4} & \frac{1}{4} \\ 0 & 1 & 1 & -1 \\ 0 & 0 & 1 & -\frac{11}{4} \\ 0 & 0 & 0 & 0 \end{pmatrix} \tag{9}$$

Thus,

$$\text{rank}(\mathbf{A}) = 3 \ < \ 4 \quad \implies \quad \text{The given points are coplanar.} \tag{10}$$

figure

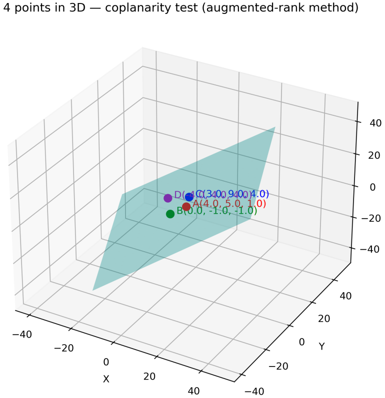

Figure: Geometric visualization of points A, B, C, D lying on the same plane.