

# Advanced Engineering Mathematics Vectors, Matrices, and Vector Calculus by Dennis G. Zill Problems

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# 1 Vectors

## 1.1 Vectors in 2-Space

### 1.1.1

- (a)  $3\mathbf{a} = 6\mathbf{i} + 12\mathbf{j}$
- (b)  $\mathbf{a} + \mathbf{b} = \mathbf{i} + 8\mathbf{j}$
- (c)  $\mathbf{a} - \mathbf{b} = 3\mathbf{i}$
- (d)  $\|\mathbf{a} + \mathbf{b}\| = \sqrt{1 + 8^2} = \sqrt{65}$
- (e)  $\|\mathbf{a} - \mathbf{b}\| = 3$

### 1.1.9

- (a)  $4\mathbf{a} - 2\mathbf{b} = \langle 6, -14 \rangle$
- (b)  $-3\mathbf{a} - 5\mathbf{b} = \langle 2, 4 \rangle$

**1.1.15**

$$\overrightarrow{P_1P_2} = \langle 2, 5 \rangle$$

**1.1.19**

$$(1, 18)$$

**1.1.21**

(a) Yes

(b) Yes

(c) Yes

(d) No

(e) Yes

(f) Yes

**1.1.25**

$$(a) \frac{\mathbf{a}}{\|\mathbf{a}\|} = \frac{\langle 2, 2 \rangle}{\sqrt{2^2+2^2}} = \frac{1}{2\sqrt{2}} \langle 2, 2 \rangle = \langle \frac{1}{\sqrt{2}}, \frac{1}{\sqrt{2}} \rangle$$

$$(b) \langle -\frac{1}{\sqrt{2}}, -\frac{1}{\sqrt{2}} \rangle$$

**1.1.31**

$$2 \frac{\mathbf{a}}{\|\mathbf{a}\|} = 2 \frac{\langle 3, 7 \rangle}{\sqrt{3^2+7^2}} = \frac{2}{\sqrt{58}} \langle 3, 7 \rangle = \langle \frac{6}{\sqrt{58}}, \frac{14}{\sqrt{58}} \rangle$$

**1.1.37**

$$\mathbf{x} = -(\mathbf{a} + \mathbf{b})$$

1.1.41

$$\mathbf{a} = 2\mathbf{i} + 3\mathbf{j}$$

$$\mathbf{b} = \mathbf{i} + \mathbf{j}$$

$$\mathbf{c} = \mathbf{i} - \mathbf{j}$$

$$\mathbf{i} = \frac{1}{2}(\mathbf{b} + \mathbf{c})$$

$$\mathbf{j} = \frac{1}{2}(\mathbf{b} - \mathbf{c})$$

$$\begin{aligned}\mathbf{a} &= 2\left(\frac{1}{2}(\mathbf{b} + \mathbf{c})\right) + 3\left(\frac{1}{2}(\mathbf{b} - \mathbf{c})\right) \\ &= \mathbf{b} + \mathbf{c} + \frac{3}{2}\mathbf{b} - \frac{3}{2}\mathbf{c} \\ &= \frac{5}{2}\mathbf{b} - \frac{1}{2}\mathbf{c}\end{aligned}$$

1.1.43

$$y = \frac{1}{4}x^2 + 1$$

$$y(2) = 2$$

$$y' = \frac{1}{2}x$$

$$y'(2) = 1$$

$$\mathbf{v} = \pm \left\langle \frac{1}{\sqrt{2}}, \frac{1}{\sqrt{2}} \right\rangle$$

1.1.45

(a)

$$\mathbf{F}_n = \mathbf{F} \cos \theta$$

$$\mathbf{F}_g = \mathbf{F} \sin \theta$$

$$||\mathbf{F}_f|| = \mu ||\mathbf{F}_n||$$

$$||-\mathbf{F}_g|| = \mu ||\mathbf{F}_n||$$

$$||-\mathbf{F} \sin \theta|| = \mu ||\mathbf{F} \cos \theta||$$

$$||\mathbf{F}|| \sin \theta = \mu ||\mathbf{F}|| \cos \theta$$

$$\tan \theta = \mu$$

(b)  $\theta = \arctan \mu \approx 31^\circ$

### 1.1.47

$$\begin{aligned}
 F_x &= \frac{qQ}{4\pi\epsilon_0} \int_{-a}^a \frac{L dy}{2a(L^2 + y^2)^{3/2}} \\
 &= \frac{LqQ}{8\pi\epsilon_0} \int_{-a}^a (L^2 + y^2)^{-3/2} dy \\
 &= \frac{LqQ}{8\pi\epsilon_0} \frac{2a}{L^2\sqrt{a^2 + L^2}} \\
 &= \frac{aqQ}{4\pi\epsilon_0 L\sqrt{a^2 + L^2}} \\
 F_y &= -\frac{qQ}{4\pi\epsilon_0} \int_{-a}^a \frac{y dy}{2a(L^2 + y^2)^{3/2}} \\
 &= 0 \\
 \mathbf{F} &= \left\langle \frac{1}{4\pi\epsilon_0} \frac{qQ}{L\sqrt{a^2 + L^2}}, 0 \right\rangle
 \end{aligned}$$

### 1.1.49

Let the three sides of the triangle be vectors  $\mathbf{a}$ ,  $\mathbf{b}$ , and  $\mathbf{c}$ . The triangle is closed so it must be the case that

$$\mathbf{a} + \mathbf{b} + \mathbf{c} = 0.$$

This gives

$$\mathbf{c} = -(\mathbf{a} + \mathbf{b}).$$

The vector from the midpoint of side  $\mathbf{a}$  to the midpoint of side  $\mathbf{b}$  is

$$\left(\mathbf{a} + \frac{1}{2}\mathbf{b}\right) - \frac{1}{2}\mathbf{a} = \frac{1}{2}(\mathbf{a} + \mathbf{b})$$

which is parallel with  $\mathbf{c}$  and half its length.

## 1.2 Vectors in 3-Space

### 1.2.7

A plane at  $z = 5$  parallel with the  $x$ - $y$  plane.

### 1.2.9

A line parallel to the  $z$  axis at  $x = 2$  and  $y = 3$ .

### 1.2.13

- (a)  $(0, 5, 4)$ ,  $(-2, 0, 4)$ ,  $(-2, 5, 0)$
- (b)  $(-2, 5, -2)$
- (c)  $(3, 5, 4)$



**1.2.15**

The planes  $x = 0$ ,  $y = 0$ , and  $z = 0$ .

**1.2.17**

$$(-1, 2, -3)$$

**1.2.19**

The planes  $z = \pm 5$ .

**1.2.21**

$$\sqrt{(6-3)^2 + (4+1)^2 + (8-2)^2} = \sqrt{9+25+36} = \sqrt{70}$$

**1.2.31**

$$\begin{aligned}\sqrt{(2-x)^2 + (1-2)^2 + (1-3)^2} &= \sqrt{21} \\ (2-x)^2 + 1 + 4 &= 21 \\ (2-x)^2 &= 16 \\ 2-x &= \pm 4 \\ x &= 2 \pm 4 \\ &= -2 \text{ or } 6\end{aligned}$$

**1.2.33**

$$(4, \frac{1}{2}, \frac{3}{2})$$

**1.2.37**

$$(-3, -6, 1)$$

**1.3 Dot Product****1.3.1**

$$\mathbf{a} \cdot \mathbf{b} = 12$$

**1.3.11**

$$\left(\frac{\mathbf{a} \cdot \mathbf{b}}{\mathbf{b} \cdot \mathbf{b}}\right) \mathbf{b} = \frac{12}{30} \mathbf{b} = \langle -\frac{2}{5}, \frac{4}{5}, 2 \rangle$$

**1.3.13**

$$\mathbf{a} \cdot \mathbf{b} = \|\mathbf{a}\| \|\mathbf{b}\| \cos \theta = 25\sqrt{2}$$

**1.3.17**

$$\mathbf{a} \cdot \mathbf{v} = 0$$

$$3x_1 + y_1 - 1 = 0$$

$$\mathbf{b} \cdot \mathbf{v} = 0$$

$$-3x_1 + 2y_2 + 2 = 0$$

$$3y_2 + 1 = 0$$

$$y_2 = -\frac{1}{3}$$

$$3x_1 - \frac{1}{3} - 1 = 0$$

$$x_1 = \frac{4}{9}$$

$$\mathbf{v} = \left\langle \frac{4}{9}, -\frac{1}{3}, 1 \right\rangle$$

**1.3.19**

$$\begin{aligned}\mathbf{a} \cdot \mathbf{c} &= \mathbf{a} \cdot \left( \mathbf{b} - \frac{\mathbf{a} \cdot \mathbf{b}}{\|\mathbf{a}\|^2} \mathbf{a} \right) \\ &= \mathbf{a} \cdot \mathbf{b} - \frac{\mathbf{a} \cdot \mathbf{b}}{\|\mathbf{a}\|^2} \mathbf{a} \cdot \mathbf{a} \\ &= 0\end{aligned}$$

**1.3.21**

$$||\mathbf{a}|| = \sqrt{3^2 + 1^2}$$

$$= \sqrt{10}$$

$$||\mathbf{b}|| = \sqrt{2^2 + 2^2}$$

$$= \sqrt{8}$$

$$= 2\sqrt{2}$$

$$\mathbf{a} \cdot \mathbf{b} = 4$$

$$\theta = \arccos \frac{\mathbf{a} \cdot \mathbf{b}}{||\mathbf{a}|| ||\mathbf{b}||}$$

$$= \arccos \frac{4}{(\sqrt{10})(2\sqrt{2})}$$

$$= \arccos \frac{1}{\sqrt{5}}$$

$$\approx 63^\circ$$

**1.3.25**

$$||\mathbf{a}|| = \sqrt{1^2 + 2^2 + 3^2}$$

$$= \sqrt{14}$$

$$\cos \alpha = \frac{1}{\sqrt{14}}$$

$$\alpha \approx 75^\circ$$

$$\cos \beta = \frac{2}{\sqrt{14}}$$

$$\beta \approx 58^\circ$$

$$\cos \gamma = \frac{3}{\sqrt{14}}$$

$$\gamma \approx 37^\circ$$

1.3.29

$$\begin{aligned}
 \overrightarrow{AD} &= \langle s, -s, s \rangle \\
 \|\overrightarrow{AD}\| &= s\sqrt{3} \\
 \overrightarrow{AB} &= \langle s, 0, 0 \rangle \\
 \|\overrightarrow{AB}\| &= s \\
 \theta &= \arccos \frac{\overrightarrow{AD} \cdot \overrightarrow{AB}}{\|\overrightarrow{AD}\| \|\overrightarrow{AB}\|} \\
 &= \arccos \frac{s^2}{s^2\sqrt{3}} \\
 &= \arccos \frac{1}{\sqrt{3}} \\
 &\approx 55^\circ
 \end{aligned}$$

1.3.33

$$\begin{aligned}
 \text{comp}_{\mathbf{b}} \mathbf{a} &= \frac{\mathbf{a} \cdot \mathbf{b}}{\|\mathbf{b}\|} \\
 &= \frac{5}{7}
 \end{aligned}$$

1.3.37

$$\begin{aligned}
 \text{comp}_{\overrightarrow{OP}} \mathbf{a} &= \frac{\mathbf{a} \cdot \overrightarrow{OP}}{\|\overrightarrow{OP}\|} \\
 &= \frac{72}{\sqrt{109}}
 \end{aligned}$$

1.3.39

$$\begin{aligned}
 \text{proj}_{\mathbf{b}} \mathbf{a} &= \left( \frac{\mathbf{a} \cdot \mathbf{b}}{\mathbf{b} \cdot \mathbf{b}} \right) \mathbf{b} \\
 &= \frac{35}{25} \mathbf{b} \\
 &= \left\langle -\frac{21}{5}, \frac{28}{5} \right\rangle
 \end{aligned}$$

**1.3.43**

$$\begin{aligned}
\mathbf{a} + \mathbf{b} &= \langle 3, 4 \rangle \\
\text{proj}_{\mathbf{a}+\mathbf{b}} \mathbf{a} &= \left( \frac{\mathbf{a} \cdot (\mathbf{a} + \mathbf{b})}{(\mathbf{a} + \mathbf{b}) \cdot (\mathbf{a} + \mathbf{b})} \right) (\mathbf{a} + \mathbf{b}) \\
&= \frac{24}{25} (\mathbf{a} + \mathbf{b}) \\
&= \left\langle \frac{72}{25}, \frac{96}{25} \right\rangle
\end{aligned}$$

**1.3.45**

$$W = \mathbf{F} \cdot \mathbf{d} = Fd \cos \theta = 1000$$

**1.3.47**

(a)  $W = 0$

(b)

$$\begin{aligned}
\|\mathbf{d}\| &= \sqrt{4^2 + 3^2} \\
&= 5
\end{aligned}$$

$$\mathbf{F} = F \hat{\mathbf{d}}$$

$$= F \frac{\mathbf{d}}{\|\mathbf{d}\|}$$

$$= F \left\langle \frac{4}{5}, \frac{3}{5} \right\rangle$$

$$= \langle 24, 18 \rangle$$

$$W = \mathbf{F} \cdot \mathbf{d}$$

$$= 150 \text{ J}$$

**1.4 Cross Product****1.4.1**

$$\begin{aligned}
\mathbf{a} \times \mathbf{b} &= \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ 1 & -1 & 0 \\ 0 & 3 & 5 \end{vmatrix} \\
&= -5\mathbf{i} - 5\mathbf{j} + 3\mathbf{k}
\end{aligned}$$

**1.4.11**

$$\begin{aligned}\overrightarrow{P_1P_2} \times \overrightarrow{P_1P_3} &= \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ -2 & 2 & -4 \\ -3 & 1 & 1 \end{vmatrix} \\ &= 6\mathbf{i} + 14\mathbf{j} + 4\mathbf{k}\end{aligned}$$

**1.4.17**

(a)

$$\begin{aligned}\mathbf{b} \times \mathbf{c} &= \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ 2 & 1 & 1 \\ 3 & 1 & 1 \end{vmatrix} \\ &= \mathbf{j} - \mathbf{k} \\ \mathbf{a} \times (\mathbf{b} \times \mathbf{c}) &= \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ 1 & -1 & 2 \\ 0 & 1 & -1 \end{vmatrix} \\ &= -\mathbf{i} + \mathbf{j} + \mathbf{k}\end{aligned}$$

**1.4.19**

$2\mathbf{k}$

**1.4.21**

$$\begin{aligned}\mathbf{k} \times (2\mathbf{i} - \mathbf{j}) &= (\mathbf{k} \times 2\mathbf{i}) - (\mathbf{k} \times \mathbf{j}) \\ &= \mathbf{i} + 2\mathbf{j}\end{aligned}$$

**1.4.23**

$$\begin{aligned}[(2\mathbf{k}) \times (3\mathbf{j})] \times (4\mathbf{j}) &= (-6\mathbf{i}) \times (4\mathbf{j}) \\ &= -24\mathbf{k}\end{aligned}$$

**1.4.37**

$12\mathbf{i} - 9\mathbf{j} + 18\mathbf{k}$

**1.4.53**

$$\begin{aligned}
\mathbf{b} \times \mathbf{c} &= \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ -2 & 6 & -6 \\ \frac{5}{2} & 3 & \frac{1}{2} \end{vmatrix} \\
&= 21\mathbf{i} - 14\mathbf{j} - 21\mathbf{k} \\
\mathbf{a} \cdot (\mathbf{b} \times \mathbf{c}) &= 4 \times 21 + 6 \times (-14) \\
&= 0
\end{aligned}$$

They are coplanar.

**1.5 Lines and Planes in 3-Space****1.5.1**

$$\mathbf{r} = \langle 1, 2, 1 \rangle + t\langle 2, 3, -3 \rangle$$

**1.5.7**

$$\begin{aligned}
x &= 2 + 4t \\
y &= 3 - 4t \\
z &= 5 + 3t
\end{aligned}$$

**1.5.13**

$$\begin{aligned}
x &= 1 + 9t \\
y &= 4 + 10t \\
z &= -9 + 7t \\
\frac{x-1}{9} &= \frac{y-4}{10} = \frac{z+9}{7}
\end{aligned}$$

**1.5.19**

$$\begin{aligned}
x &= 4 + 3t \\
y &= 6 + \frac{1}{2}t \\
z &= -7 - \frac{3}{2}t \\
\frac{x-4}{3} &= \frac{y-6}{1/2} = -\frac{z+7}{3/2}
\end{aligned}$$

**1.5.23**

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

**1.5.25**

$$\begin{aligned}x &= 2 + t \\y &= -2 \\z &= 15\end{aligned}$$

**1.5.29**

$$(0, 5, 15), (5, 0, \frac{15}{2}), (10, -5, 0)$$

**1.5.31**

$$\begin{aligned}4 + t_x &= 6 + 2t_x \\t_x &= -2\end{aligned}$$

$$\begin{aligned}5 + t_y &= 11 + 4t_y \\t_y &= -2\end{aligned}$$

$$\begin{aligned}-1 + 2t_z &= -3 + t_z \\t_z &= -2\end{aligned}$$

$$(2, 3, -5)$$

**1.5.35**

$$\begin{aligned}\mathbf{a} &= \langle -1, 2, -2 \rangle \\||\mathbf{a}|| &= 3 \\ \mathbf{b} &= \langle 2, 3, -6 \rangle \\||\mathbf{b}|| &= 7 \\ \theta &= \arccos \frac{\mathbf{a} \cdot \mathbf{b}}{||\mathbf{a}|| ||\mathbf{b}||} \\ &\approx 40.37^\circ\end{aligned}$$



1.5.37

$$\begin{aligned}\mathbf{a} &= \langle 1, 1, 1 \rangle \\ \mathbf{b} &= \langle -2, 1, -5 \rangle \\ \mathbf{a} \times \mathbf{b} &= \begin{vmatrix} \hat{\mathbf{i}} & \hat{\mathbf{j}} & \hat{\mathbf{k}} \\ 1 & 1 & 1 \\ -2 & 1 & -5 \end{vmatrix} \\ &= \langle -6, 3, 3 \rangle \\ x &= 4 - 6t \\ y &= 1 + 3t \\ z &= 6 + 3t\end{aligned}$$

1.5.39

$$\begin{aligned}\langle 2, -3, 4 \rangle \cdot (\mathbf{r} - \langle 5, 1, 3 \rangle) &= 0 \\ 2(x - 5) - 3(y - 1) + 4(z - 3) &= 0 \\ 2x - 3y + 4z - 19 &= 0\end{aligned}$$

1.5.45

$$\begin{aligned}\mathbf{a} &= \langle 3, 5, 2 \rangle \\ \mathbf{b} &= \langle 2, 3, 1 \rangle \\ \mathbf{c} &= \langle -1, -1, 4 \rangle \\ \mathbf{a} - \mathbf{c} &= \langle 4, 6, -2 \rangle \\ \mathbf{b} - \mathbf{c} &= \langle 3, 4, -3 \rangle \\ (\mathbf{a} - \mathbf{c}) \times (\mathbf{b} - \mathbf{c}) &= \begin{vmatrix} \hat{\mathbf{i}} & \hat{\mathbf{j}} & \hat{\mathbf{k}} \\ 4 & 6 & -2 \\ 3 & 4 & -3 \end{vmatrix} \\ &= \langle -10, 6, -2 \rangle \\ \mathbf{n} \cdot (\mathbf{r} - \mathbf{c}) &= 0 \\ \langle -10, 6, -2 \rangle \cdot (\langle x, y, z \rangle - \langle -1, -1, 4 \rangle) &= 0 \\ -10(x + 1) + 6(y + 1) - 2(z - 4) &= 0 \\ -10x + 6y - 2z + 4 &= 0\end{aligned}$$

1.5.51

$$\begin{aligned}\langle 1, 1, -4 \rangle \cdot (\mathbf{r} - \langle 2, 3, -5 \rangle) &= 0 \\ (x - 2) + (y - 3) - 4(z + 5) &= 0 \\ x + y - 4z &= 25\end{aligned}$$

**1.5.63**

- (a) Not perpendicular
- (b) Not perpendicular
- (c) Perpendicular
- (d) Perpendicular

**1.5.65**

$$5x - 4y - 9t = 8$$

$$x + 4y + 3t = 4$$

$$6x - 6t = 12$$

$$x = 2 + t$$

$$y = \frac{1}{2} - t$$

$$z = t$$

**1.5.69**

$$2(1 + 2t) - 3(2 - t) + 2(-3t) = -7$$

$$t = -3$$

$$x = -5$$

$$y = 5$$

$$z = 9$$

**1.5.73**

$$\begin{aligned}x + y - 4t &= 2 \\ 2x - y + t &= 10\end{aligned}$$

$$\begin{aligned}3x - 3t &= 12 \\ x &= 4 + t\end{aligned}$$

$$\begin{aligned}2(4 + t) - y + t &= 10 \\ 8 + 2t - y + t &= 10 \\ y &= -2 + 3t\end{aligned}$$

$$z = t$$

$$\begin{aligned}x &= 5 + t \\ y &= 6 + 3t \\ z &= -12 + t\end{aligned}$$

**1.5.75**

$$\begin{aligned}\mathbf{n} &= \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ 3 & -1 & 5 \\ 1 & 1 & 1 \end{vmatrix} \\ &= \langle -6, 2, 4 \rangle\end{aligned}$$

$$\begin{aligned}\mathbf{n} \cdot (\mathbf{r} - \langle 4, 0, 1 \rangle) &= 0 \\ -6(x - 4) + 2y + 4(z - 1) &= 0 \\ -6x + 2y + 4z &= -20 \\ 3x - y - 2z &= 10\end{aligned}$$

**1.6 Vector Spaces****1.6.1**

Violates axiom 6

**1.6.3**

Violates axiom 10

**1.6.5**

Vector space

**1.6.7**

Violates axiom 2

**1.6.9**

Vector space

**1.6.11**

Subspace

**1.6.13**

Not a subspace

**1.6.15**

Subspace

**1.6.17**

Subspace

**1.6.19**

Not a subspace

**1.6.23**

(a)

$$k_1 \mathbf{u}_1 + k_2 \mathbf{u}_2 + k_3 \mathbf{u}_3 = \mathbf{0}$$

$$k_1 \langle 1, 0, 0 \rangle + k_2 \langle 1, 1, 0 \rangle + k_3 \langle 1, 1, 1 \rangle = \mathbf{0}$$

$$k_3 = 0$$

$$k_2 + k_3 = 0$$

$$k_2 = 0$$

$$k_1 + k_2 + k_3 = 0$$

$$k_1 = 0$$

(b)

$$\mathbf{a} = 7\mathbf{u}_1 - 12\mathbf{u}_2 + 8\mathbf{u}_3$$

**1.6.25**

Dependent

**1.6.27**

Independent

**1.6.29** $f(x)$  is undefined at  $x = -3$  and  $x = -1$ .**1.6.31**

$$\begin{aligned}
||x|| &= \sqrt{(x, x)} \\
&= \sqrt{\int_0^{2\pi} x^2 dx} \\
&= \sqrt{\left[\frac{1}{3}x^3\right]_0^{2\pi}} \\
&= \sqrt{\frac{8}{3}\pi^3} \\
||\sin x|| &= \sqrt{(\sin x, \sin x)} \\
&= \sqrt{\int_0^{2\pi} \sin^2 x dx} \\
&= \sqrt{\left[\frac{x}{2} - \frac{1}{4}\sin 2x\right]_0^{2\pi}} \\
&= \sqrt{\pi}
\end{aligned}$$

## 1.7 Gram–Schmidt Orthogonalization Process

### 1.7.1

$$\begin{aligned}\left\langle \frac{12}{13}, \frac{5}{13} \right\rangle \cdot \left\langle \frac{5}{13}, -\frac{12}{13} \right\rangle &= 0 \\ \sqrt{\left(\frac{12}{13}\right)^2 + \left(\frac{5}{13}\right)^2} &= 1 \\ \mathbf{u} &= \left( \left\langle 4, 2 \right\rangle \cdot \left\langle \frac{12}{13}, \frac{5}{13} \right\rangle \right) \left\langle \frac{12}{13}, \frac{5}{13} \right\rangle \\ &\quad + \left( \left\langle 4, 2 \right\rangle \cdot \left\langle \frac{5}{13}, -\frac{12}{13} \right\rangle \right) \left\langle \frac{5}{13}, -\frac{12}{13} \right\rangle \\ &= \left( \frac{58}{13} \right) \left\langle \frac{12}{13}, \frac{5}{13} \right\rangle - \left( \frac{4}{13} \right) \left\langle \frac{5}{13}, -\frac{12}{13} \right\rangle\end{aligned}$$

### 1.7.3

$$\begin{aligned}\langle 1, 0, 1 \rangle \cdot \langle 0, 1, 0 \rangle &= 0 \\ \langle 1, 0, 1 \rangle \cdot \langle -1, 0, 1 \rangle &= 0 \\ \langle 0, 1, 0 \rangle \cdot \langle -1, 0, 1 \rangle &= 0 \\ B' &= \left\{ \left\langle \frac{1}{\sqrt{2}}, 0, \frac{1}{\sqrt{2}} \right\rangle, \langle 0, 1, 0 \rangle, \left\langle -\frac{1}{\sqrt{2}}, 0, \frac{1}{\sqrt{2}} \right\rangle \right\} \\ \mathbf{u} &= -\frac{3}{\sqrt{2}} \left\langle \frac{1}{\sqrt{2}}, 0, \frac{1}{\sqrt{2}} \right\rangle + 7 \langle 0, 1, 0 \rangle - \frac{23}{\sqrt{2}} \left\langle -\frac{1}{\sqrt{2}}, 0, \frac{1}{\sqrt{2}} \right\rangle\end{aligned}$$

**1.7.5**

(a)

$$B = \{\langle -3, 2 \rangle, \langle -1, -1 \rangle\}$$

$$\mathbf{v}_1 = \mathbf{u}_1$$

$$= \langle -3, 2 \rangle$$

$$\mathbf{v}_2 = \mathbf{u}_2 - \text{proj}_{\mathbf{v}_1} \mathbf{u}_2$$

$$= \langle -1, -1 \rangle - \left( \frac{\langle -1, -1 \rangle \cdot \langle -3, 2 \rangle}{\langle -3, 2 \rangle \cdot \langle -3, 2 \rangle} \right) \langle -3, 2 \rangle$$

$$= \langle -1, -1 \rangle - \frac{1}{13} \langle -3, 2 \rangle$$

$$= \left\langle -\frac{10}{13}, -\frac{15}{13} \right\rangle$$

$$\mathbf{w}_1 = \left\langle -\frac{3}{\sqrt{13}}, \frac{2}{\sqrt{13}} \right\rangle$$

$$\mathbf{w}_2 = \sqrt{\frac{169}{325}} \left\langle -\frac{10}{13}, -\frac{15}{13} \right\rangle$$

$$= \frac{\sqrt{13}}{5} \left\langle -\frac{10}{13}, -\frac{15}{13} \right\rangle$$

$$= \left\langle -\frac{2}{\sqrt{13}}, -\frac{3}{\sqrt{13}} \right\rangle$$

1.7.9

$$B = \{\langle 1, 1, 0 \rangle, \langle 1, 2, 2 \rangle, \langle 2, 2, 1 \rangle\}$$

$$\mathbf{v}_1 = \langle 1, 1, 0 \rangle$$

$$\mathbf{v}_2 = \mathbf{u}_2 - \text{proj}_{\mathbf{v}_1} \mathbf{u}_2$$

$$= \langle 1, 2, 2 \rangle - \left( \frac{\langle 1, 2, 2 \rangle \cdot \langle 1, 1, 0 \rangle}{\langle 1, 1, 0 \rangle \cdot \langle 1, 1, 0 \rangle} \right) \langle 1, 1, 0 \rangle$$

$$= \langle 1, 2, 2 \rangle - \frac{3}{2} \langle 1, 1, 0 \rangle$$

$$= \langle -\frac{1}{2}, \frac{1}{2}, 2 \rangle$$

$$\mathbf{v}_3 = \mathbf{u}_3 - \text{proj}_{\mathbf{v}_1} \mathbf{u}_3 - \text{proj}_{\mathbf{v}_2} \mathbf{u}_3$$

$$= \langle 2, 2, 1 \rangle - \left( \frac{\langle 2, 2, 1 \rangle \cdot \langle 1, 1, 0 \rangle}{\langle 1, 1, 0 \rangle \cdot \langle 1, 1, 0 \rangle} \right) \langle 1, 1, 0 \rangle$$

$$- \left( \frac{\langle 2, 2, 1 \rangle \cdot \langle -\frac{1}{2}, \frac{1}{2}, 2 \rangle}{\langle -\frac{1}{2}, \frac{1}{2}, 2 \rangle \cdot \langle -\frac{1}{2}, \frac{1}{2}, 2 \rangle} \right) \langle -\frac{1}{2}, \frac{1}{2}, 2 \rangle$$

$$= \langle 2, 2, 1 \rangle - 2 \langle 1, 1, 0 \rangle - \frac{4}{9} \langle -\frac{1}{2}, \frac{1}{2}, 2 \rangle$$

$$= \langle \frac{2}{9}, -\frac{2}{9}, \frac{1}{9} \rangle$$

$$\mathbf{w}_1 = \langle \frac{1}{\sqrt{2}}, \frac{1}{\sqrt{2}}, 0 \rangle$$

$$\mathbf{w}_2 = \langle -\frac{1}{3\sqrt{2}}, \frac{1}{3\sqrt{2}}, \frac{4}{3\sqrt{2}} \rangle$$

$$\mathbf{w}_3 = 3 \langle \frac{2}{9}, -\frac{2}{9}, \frac{1}{9} \rangle$$

$$= \langle \frac{2}{3}, -\frac{2}{3}, \frac{1}{3} \rangle$$



1.7.17

$$B = \{1, x, x^2\}$$

$$\mathbf{v}_1 = \mathbf{u}_1$$

$$= 1$$

$$\mathbf{v}_2 = \mathbf{u}_2 - \text{proj}_{\mathbf{v}_1} \mathbf{u}_2$$

$$= \mathbf{u}_2 - \left( \frac{\mathbf{u}_2 \cdot \mathbf{v}_1}{\mathbf{v}_1 \cdot \mathbf{v}_1} \right) \mathbf{v}_1$$

$$= x - \frac{\int_{-1}^1 x \, dx}{\int_{-1}^1 dx}$$

$$= x - \frac{\left[ \frac{1}{2} x^2 \right]_{-1}^1}{2}$$

$$= x$$

$$\mathbf{v}_3 = \mathbf{u}_3 - \text{proj}_{\mathbf{v}_1} \mathbf{u}_3 - \text{proj}_{\mathbf{v}_2} \mathbf{u}_3$$

$$= \mathbf{u}_3 - \left( \frac{\mathbf{u}_3 \cdot \mathbf{v}_1}{\mathbf{v}_1 \cdot \mathbf{v}_1} \right) \mathbf{v}_1 - \left( \frac{\mathbf{u}_3 \cdot \mathbf{v}_2}{\mathbf{v}_2 \cdot \mathbf{v}_2} \right) \mathbf{v}_2$$

$$= x^2 - \frac{\int_{-1}^1 x^2 \, dx}{\int_{-1}^1 dx} - \frac{\int_{-1}^1 x^3 \, dx}{\int_{-1}^1 x^2 \, dx} x$$

$$= x^2 - \frac{\left[ \frac{1}{3} x^3 \right]_{-1}^1}{2} - \frac{\left[ \frac{1}{4} x^4 \right]_{-1}^1}{\left[ \frac{1}{3} x^3 \right]_{-1}^1} x$$

$$= x^2 - \frac{1}{3}$$

1.7.19

$$\begin{aligned}
\|\mathbf{v}_1\|^2 &= \int_{-1}^1 dx \\
&= 2 \\
\mathbf{w}_1 &= \frac{1}{\sqrt{2}} \\
\|\mathbf{v}_2\|^2 &= \int_{-1}^1 x^2 dx \\
&= \left[ \frac{1}{3} x^3 \right]_{-1}^1 \\
&= \frac{2}{3} \\
\mathbf{w}_2 &= \frac{\sqrt{3}}{\sqrt{6}} x \\
\|\mathbf{v}_3\|^2 &= \int_{-1}^1 \left( x^2 - \frac{1}{3} \right)^2 dx \\
&= \int_{-1}^1 \left( x^4 - \frac{2}{3} x^2 + \frac{1}{9} \right) dx \\
&= \left[ \frac{1}{5} x^5 - \frac{2}{9} x^3 + \frac{1}{9} x \right]_{-1}^1 \\
&= \frac{1}{5} - \frac{2}{9} + \frac{1}{9} + \frac{1}{5} - \frac{2}{9} + \frac{1}{9} \\
&= \frac{2}{5} - \frac{2}{9} \\
&= \frac{8}{45} \\
\mathbf{w}_3 &= \sqrt{\frac{45}{8}} \left( x^2 - \frac{1}{3} \right) \\
&= \frac{5}{2\sqrt{10}} (3x^2 - 1)
\end{aligned}$$

1.7.21

$$\begin{aligned}
(\mathbf{p}, \mathbf{w}_1) &= \int_{-1}^1 \frac{1}{\sqrt{2}} (9x^2 - 6x + 5) dx \\
&= \frac{1}{\sqrt{2}} [3x^3 - 3x^2 + 5x]_{-1}^1 \\
&= \frac{1}{\sqrt{2}} (3 - 3 + 5 + 3 + 3 + 5) \\
&= \frac{16}{\sqrt{2}} \\
(\mathbf{p}, \mathbf{w}_2) &= \int_{-1}^1 \frac{3}{\sqrt{6}} x (9x^2 - 6x + 5) dx \\
&= \frac{3}{\sqrt{6}} \left[ \frac{9}{4} x^4 - 2x^3 + \frac{5}{2} x^2 \right]_{-1}^1 \\
&= \frac{3}{\sqrt{6}} \left( \frac{9}{4} - 2 + \frac{5}{2} - \frac{9}{4} - 2 - \frac{5}{2} \right) \\
&= \frac{3}{\sqrt{6}} \left( \frac{9}{4} - \frac{8}{4} + \frac{10}{4} - \frac{9}{4} - \frac{8}{4} - \frac{10}{4} \right) \\
&= -\frac{12}{\sqrt{6}} \\
(\mathbf{p}, \mathbf{w}_3) &= \int_{-1}^1 \frac{5}{2\sqrt{10}} (3x^2 - 1)(9x^2 - 6x + 5) dx \\
&= \frac{5}{2\sqrt{10}} \int_{-1}^1 (27x^4 - 18x^3 + 6x^2 + 6x - 5) dx \\
&= \frac{5}{2\sqrt{10}} \left[ \frac{27}{5} x^5 - \frac{9}{2} x^4 + 2x^3 + 3x^2 - 5x \right]_{-1}^1 \\
&= \frac{5}{2\sqrt{10}} \left( \frac{27}{5} - \frac{9}{2} + 2 + 3 - 5 + \frac{27}{5} + \frac{9}{2} + 2 - 3 - 5 \right) \\
&= \frac{5}{2\sqrt{10}} \left( \frac{54}{10} - \frac{45}{10} + \frac{20}{10} + \frac{30}{10} - \frac{50}{10} + \frac{54}{10} + \frac{45}{10} + \frac{20}{10} - \frac{30}{10} - \frac{50}{10} \right) \\
&= \frac{5}{2\sqrt{10}} \frac{48}{10} \\
&= \frac{12}{\sqrt{10}} \\
\mathbf{p} &= \frac{16}{\sqrt{2}} \mathbf{w}_1 - \frac{12}{\sqrt{6}} \mathbf{w}_2 + \frac{12}{\sqrt{10}} \mathbf{w}_3
\end{aligned}$$

## 1.8 Chapter in Review

### 1.8.1

True

### 1.8.3

$$\mathbf{u} = \langle 5, -2, 1 \rangle$$

$$\mathbf{v} = \langle 2, 3, -4 \rangle$$

False

### 1.8.5

True

### 1.8.7

True

### 1.8.9

True

### 1.8.11

$$9\mathbf{i} + 2\mathbf{j} + 2\mathbf{k}$$

### 1.8.13

$$\begin{aligned} (-\mathbf{k}) \times (5\mathbf{j}) &= \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ 0 & 0 & -1 \\ 0 & 5 & 0 \end{vmatrix} \\ &= 5\mathbf{i} \end{aligned}$$

### 1.8.15

$$\| -12\mathbf{i} + 4\mathbf{j} + 6\mathbf{k} \| = \sqrt{12^2 + 4^2 + 6^2} = 14$$

### 1.8.17

$$\langle -6, 1, -7 \rangle$$

**1.8.19**

$$\begin{aligned}x &= 1 + t \\y &= -2 + 3t \\z &= -1 + 2t\end{aligned}$$

$$\begin{aligned}x + 2y - z &= 13 \\(1 + t) + 2(-2 + 3t) - (-1 + 2t) &= 13 \\1 + t - 4 + 6t + 1 - 2t &= 13 \\-2 + 5t &= 13 \\t &= 3\end{aligned}$$

$$\begin{aligned}x &= 4 \\y &= 7 \\z &= 5\end{aligned}$$

**1.8.21**

$$\begin{aligned}\overrightarrow{P_1P_2} &= \vec{P_2} - \vec{P_1} \\ \vec{P_2} &= \overrightarrow{P_1P_2} + \vec{P_1} \\ &= \langle 3, 5, -4 \rangle + \langle 2, 1, 7 \rangle \\ &= \langle 5, 6, 3 \rangle\end{aligned}$$

**1.8.23**

$$\mathbf{a} \cdot \mathbf{b} = -36\sqrt{2}$$

**1.8.25**

$$x = 12, y = -8, z = 6$$

**1.8.27**

$$\begin{aligned}\frac{1}{2}(\mathbf{a} \times \mathbf{b}) &= \frac{1}{2} \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ 1 & 3 & -1 \\ 2 & -1 & 2 \end{vmatrix} \\ &= \frac{1}{2} \langle 5, -4, -7 \rangle \\ &= \left\langle \frac{5}{2}, -2, -\frac{7}{2} \right\rangle\end{aligned}$$

The area is  $\sqrt{\left(\frac{5}{2}\right)^2 + (-2)^2 + \left(-\frac{7}{2}\right)^2} = \frac{3}{2}\sqrt{10}$

**1.8.29**

2

**1.8.31**

$$\begin{aligned}\mathbf{a} \times \mathbf{b} &= \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ 1 & 1 & 0 \\ 1 & -2 & 1 \end{vmatrix} \\ &= \langle 1, -1, -3 \rangle \\ \|\mathbf{a} \times \mathbf{b}\| &= \sqrt{11} \\ \text{norm}(\mathbf{a} \times \mathbf{b}) &= \left\langle \frac{1}{\sqrt{11}}, -\frac{1}{\sqrt{11}}, -\frac{3}{\sqrt{11}} \right\rangle\end{aligned}$$

**1.8.33**

$$\text{comp}_{\mathbf{b}} \mathbf{a} = \frac{\mathbf{a} \cdot \mathbf{b}}{\|\mathbf{b}\|} = \frac{10}{5} = 2$$

**1.8.35**

$$\begin{aligned}\mathbf{a} &= \langle 1, 2, -2 \rangle \\ \mathbf{b} &= \langle 4, 3, 0 \rangle \\ \mathbf{a} + \mathbf{b} &= \langle 5, 5, -2 \rangle \\ \text{proj}_{\mathbf{a}}(\mathbf{a} + \mathbf{b}) &= \left( \frac{(\mathbf{a} + \mathbf{b}) \cdot \mathbf{a}}{\mathbf{a} \cdot \mathbf{a}} \right) \mathbf{a} \\ &= \frac{19}{9} \langle 1, 2, -2 \rangle \\ &= \left\langle \frac{19}{9}, \frac{38}{9}, -\frac{38}{9} \right\rangle\end{aligned}$$

**1.8.37**

(a)

(b) A plane with normal  $\mathbf{a}$

**1.8.39**

$$\frac{x-7}{4} = \frac{y-3}{-2} = \frac{z+5}{6}$$

**1.8.41**

$$\begin{aligned}\langle -2, 3, 1 \rangle \cdot \langle 2, 1, 1 \rangle &= -4 + 3 + 1 \\ &= 0\end{aligned}$$

$$\begin{aligned}1 - 2t &= 1 + 2s \\ t &= -s\end{aligned}$$

$$3t = -4 + s$$

$$\begin{aligned}t &= -\frac{4}{3} + \frac{s}{3} \\ &= -\frac{4}{3} - \frac{t}{3}\end{aligned}$$

$$\begin{aligned}\frac{4}{3}t &= -\frac{4}{3} \\ t &= -1\end{aligned}$$

$$s = 1$$

$$\langle 3, -3, 0 \rangle$$

**1.8.43**

$$\mathbf{u} = \langle 1, 4, -2 \rangle$$

$$\mathbf{v} = \langle 1, 1, 3 \rangle$$

$$\mathbf{n} = \mathbf{u} \times \mathbf{v}$$

$$= \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ 1 & 4 & -2 \\ 1 & 1 & 3 \end{vmatrix}$$

$$= \langle 14, -5, -3 \rangle$$

$$\mathbf{n} \cdot (\mathbf{r} - \mathbf{v}) = 0$$

$$\langle 14, -5, -3 \rangle \cdot (\langle x, y, z \rangle - \langle 1, 1, 3 \rangle) = 0$$

$$14(x - 1) - 5(y - 1) - 3(z - 3) = 0$$

$$14x - 5y - 3z = 0$$

**1.8.45**

$$\begin{aligned}\mathbf{F} &= \left\langle \frac{10}{\sqrt{2}}, \frac{10}{\sqrt{2}}, 0 \right\rangle \\ \mathbf{d} &= \langle 3, 3, 0 \rangle \\ \mathbf{F} \cdot \mathbf{d} &= 30\sqrt{2} \text{ J}\end{aligned}$$

**1.8.47**

$$\begin{aligned}\mathbf{F}_1 &= \langle 200, 0, 0 \rangle \\ \mathbf{F}_2 &= \left\langle \frac{200}{\sqrt{2}}, \frac{200}{\sqrt{2}}, 0 \right\rangle \\ \mathbf{F}_2 &= \mathbf{F}_1 + \mathbf{F}_3 \\ \mathbf{F}_3 &= \mathbf{F}_2 - \mathbf{F}_1 \\ &= \left\langle \frac{200}{\sqrt{2}}, \frac{200}{\sqrt{2}}, 0 \right\rangle - \langle 200, 0, 0 \rangle \\ &= \left\langle \frac{200}{\sqrt{2}} - 200, \frac{200}{\sqrt{2}}, 0 \right\rangle \\ \|\mathbf{F}_3\| &= \sqrt{\left(\frac{200}{\sqrt{2}} - 200\right)^2 + \left(\frac{200}{\sqrt{2}}\right)^2} \\ &= \sqrt{\frac{40000}{2} - \frac{80000}{\sqrt{2}} + 40000 + \frac{40000}{2}} \\ &= 200\sqrt{2\left(1 - \frac{1}{\sqrt{2}}\right)} \\ &\approx 153 \text{ lb}\end{aligned}$$

## **2 Matrices**

### **2.1 Matrix Algebra**

#### **2.1.1**

$$2 \times 4$$

#### **2.1.3**

$$3 \times 3$$

#### **2.1.5**

$$3 \times 4$$



**2.1.7**

No

**2.1.9**

No

**2.1.11**

$$\begin{aligned}x &= y - 2 \\ 3x - 2 &= y\end{aligned}$$

$$\begin{aligned}2x - 2 &= 2 \\ 2x &= 4 \\ x &= 2\end{aligned}$$

$$\begin{aligned}2 &= y - 2 \\ y &= 4\end{aligned}$$

**2.1.13**

$$\begin{aligned}c_{23} &= 9 \\ c_{12} &= 12\end{aligned}$$

**2.1.15**

$$(a) \begin{pmatrix} 2 & 11 \\ 2 & -1 \end{pmatrix}$$

$$(b) \begin{pmatrix} -6 & 1 \\ 14 & -19 \end{pmatrix}$$

$$(c) \begin{pmatrix} 2 & 28 \\ 12 & -12 \end{pmatrix}$$

**2.1.17**

$$(a) \begin{pmatrix} -11 & 6 \\ 17 & -22 \end{pmatrix}$$

$$(b) \begin{pmatrix} -32 & 27 \\ -4 & -1 \end{pmatrix}$$

$$(c) \begin{pmatrix} 19 & -18 \\ -30 & 31 \end{pmatrix}$$

$$(d) \begin{pmatrix} 19 & 6 \\ 3 & 22 \end{pmatrix}$$

**2.1.21**

$$(a) \ 180$$

$$(b) \begin{pmatrix} 4 & 8 & 10 \\ 8 & 16 & 20 \\ 10 & 20 & 25 \end{pmatrix}$$

$$(c) \begin{pmatrix} 6 \\ 12 \\ -5 \end{pmatrix}$$

**2.1.23**

$$(a) \begin{pmatrix} 7 & 38 \\ 10 & 75 \end{pmatrix}$$

$$(b) \begin{pmatrix} 7 & 38 \\ 10 & 75 \end{pmatrix}$$

**2.1.25**

$$\begin{pmatrix} -14 \\ 1 \end{pmatrix}$$

**2.1.27**

$$\begin{pmatrix} -38 \\ -2 \end{pmatrix}$$

**2.1.29**

$$4 \times 5$$

**2.1.41**

$$a_{11}x_1 + a_{12}x_2 = b_1$$

$$a_{21}x_1 + a_{22}x_2 = b_2$$

**2.1.43**

$$\begin{aligned} \begin{pmatrix} x & y \end{pmatrix} \begin{pmatrix} a & \frac{1}{2}b \\ \frac{1}{2}b & c \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix} &= \begin{pmatrix} x & y \end{pmatrix} \begin{pmatrix} ax + \frac{1}{2}by \\ \frac{1}{2}bx + cy \end{pmatrix} \\ &= ax^2 + \frac{1}{2}bxy + \frac{1}{2}bxy + cy^2 \\ &= ax^2 + bxy + cy^2 \end{aligned}$$

**2.1.45**

$$\langle -1, 1 \rangle$$

**2.1.47**

$$\langle -2, 0 \rangle$$

**2.1.49**

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

**2.1.51**

(b)

$$\begin{pmatrix} x_S \\ y_S \\ z_S \end{pmatrix} = \begin{pmatrix} \cos \gamma & \sin \gamma & 0 \\ -\sin \gamma & \cos \gamma & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \cos \beta & 0 & -\sin \beta \\ 0 & 1 & 0 \\ \sin \beta & 0 & \cos \beta \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos \alpha & \sin \alpha \\ 0 & -\sin \alpha & \cos \alpha \end{pmatrix} \begin{pmatrix} x \\ y \\ z \end{pmatrix}$$

## 2.2 Systems of Linear Algebraic Equations

**2.2.1**

$$\begin{pmatrix} 1 & -1 & | & 11 \\ 4 & 3 & | & -5 \end{pmatrix}$$
$$\begin{pmatrix} 1 & -1 & | & 11 \\ 0 & 7 & | & -49 \end{pmatrix}$$
$$\begin{pmatrix} 1 & -1 & | & 11 \\ 0 & 1 & | & -7 \end{pmatrix}$$
$$\begin{pmatrix} 1 & 0 & | & 4 \\ 0 & 1 & | & -7 \end{pmatrix}$$

### 2.2.5

$$\begin{pmatrix} 1 & -1 & -1 & | & -3 \\ 2 & 3 & 5 & | & 7 \\ 1 & -2 & 3 & | & -11 \end{pmatrix} \\
 \begin{pmatrix} 1 & -1 & -1 & | & -3 \\ 0 & 5 & 7 & | & 13 \\ 0 & -1 & 4 & | & -8 \end{pmatrix} \\
 \begin{pmatrix} 1 & -1 & -1 & | & -3 \\ 0 & 1 & \frac{7}{5} & | & \frac{13}{5} \\ 0 & -1 & 4 & | & -8 \end{pmatrix} \\
 \begin{pmatrix} 1 & -1 & -1 & | & -3 \\ 0 & 1 & \frac{7}{5} & | & \frac{13}{5} \\ 0 & 0 & \frac{27}{5} & | & -\frac{27}{5} \end{pmatrix} \\
 \begin{pmatrix} 1 & -1 & -1 & | & -3 \\ 0 & 1 & \frac{7}{5} & | & \frac{13}{5} \\ 0 & 0 & 1 & | & -1 \end{pmatrix} \\
 \begin{pmatrix} 1 & -1 & 0 & | & -4 \\ 0 & 1 & 0 & | & 4 \\ 0 & 0 & 1 & | & -1 \end{pmatrix} \\
 \begin{pmatrix} 1 & 0 & 0 & | & 0 \\ 0 & 1 & 0 & | & 4 \\ 0 & 0 & 1 & | & -1 \end{pmatrix}$$

## 2.3 Rank of a Matrix

### 2.3.1

$$\begin{pmatrix} 3 & -1 \\ 1 & 3 \end{pmatrix} \\
 \begin{pmatrix} 1 & -\frac{1}{3} \\ 1 & 3 \end{pmatrix} \\
 \begin{pmatrix} 1 & -\frac{1}{3} \\ 0 & \frac{10}{3} \end{pmatrix}$$

Rank 2

### 2.3.3

$$\begin{pmatrix} 2 & 1 & 3 \\ 6 & 3 & 9 \\ -1 & -\frac{1}{2} & -\frac{3}{2} \end{pmatrix}$$
$$\begin{pmatrix} 1 & \frac{1}{2} & \frac{3}{2} \\ 6 & 3 & 9 \\ -1 & -\frac{1}{2} & -\frac{3}{2} \end{pmatrix}$$
$$\begin{pmatrix} 1 & \frac{1}{2} & \frac{3}{2} \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

Rank 1

### 2.3.5

$$\begin{pmatrix} 1 & 1 & 1 \\ 1 & 0 & 4 \\ 1 & 4 & 1 \end{pmatrix}$$
$$\begin{pmatrix} 1 & 1 & 1 \\ 0 & -1 & 3 \\ 0 & 3 & 0 \end{pmatrix}$$
$$\begin{pmatrix} 1 & 1 & 1 \\ 0 & 1 & -3 \\ 0 & 3 & 0 \end{pmatrix}$$
$$\begin{pmatrix} 1 & 1 & 1 \\ 0 & 1 & -3 \\ 0 & 0 & 9 \end{pmatrix}$$
$$\begin{pmatrix} 1 & 1 & 1 \\ 0 & 1 & -3 \\ 0 & 0 & 1 \end{pmatrix}$$

Rank 3

**2.3.7**

$$\begin{pmatrix} 1 & -2 \\ 3 & -6 \\ 7 & -1 \\ 4 & 5 \end{pmatrix}$$

$$\begin{pmatrix} 1 & -2 \\ 0 & 13 \\ 0 & 13 \\ 0 & 0 \end{pmatrix}$$

$$\begin{pmatrix} 1 & -2 \\ 0 & 13 \\ 0 & 0 \\ 0 & 0 \end{pmatrix}$$

Rank 2

**2.3.11**

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

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

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

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

Linearly independent

**2.3.15**

5

**2.3.17**

$\text{rank}(\mathbf{A}) = 2$

## 2.4 Determinants

### 2.4.1

9

### 2.4.3

1

### 2.4.5

$$\begin{aligned}M_{33} &= \begin{vmatrix} 0 & 2 & 0 \\ 1 & 2 & 3 \\ 1 & 1 & 2 \end{vmatrix} \\&= -2 \begin{vmatrix} 1 & 3 \\ 1 & 2 \end{vmatrix} \\&= 2\end{aligned}$$

### 2.4.7

$$\begin{aligned}C_{34} &= (-1)^{3+4} \begin{vmatrix} 0 & 2 & 4 \\ 1 & 2 & -2 \\ 1 & 1 & 1 \end{vmatrix} \\&= - \left( -2 \begin{vmatrix} 1 & -2 \\ 1 & 1 \end{vmatrix} + 4 \begin{vmatrix} 1 & 2 \\ 1 & 1 \end{vmatrix} \right) \\&= 10\end{aligned}$$

### 2.4.9

-7

### 2.4.11

17

### 2.4.13

$$\begin{aligned}(1 - \lambda)(2 - \lambda) - 6 &= 2 - \lambda - 2\lambda + \lambda^2 - 6 \\&= \lambda^2 - 3\lambda - 4 \\&= (\lambda + 1)(\lambda - 4)\end{aligned}$$

### 2.4.15

-48

**2.4.23**

$$\begin{aligned}\begin{vmatrix} 1 & 1 & 1 \\ x & y & z \\ 2 & 3 & 4 \end{vmatrix} &= \begin{vmatrix} y & z \\ 3 & 4 \end{vmatrix} - \begin{vmatrix} x & z \\ 2 & 4 \end{vmatrix} + \begin{vmatrix} x & y \\ 2 & 3 \end{vmatrix} \\ &= 4y - 3z - 4x + 2z + 3x - 2y \\ &= -x + 2y - z\end{aligned}$$

**2.4.29**

$$\begin{aligned}\begin{vmatrix} (-3 - \lambda) & 10 \\ 2 & (5 - \lambda) \end{vmatrix} &= 0 \\ (-3 - \lambda)(5 - \lambda) - 20 &= 0 \\ -15 + 3\lambda - 5\lambda + \lambda^2 - 20 &= 0 \\ \lambda^2 - 2\lambda - 35 &= 0 \\ (\lambda - 7)(\lambda + 5) &= 0 \\ \lambda &= -5 \text{ or } 7\end{aligned}$$

## **2.5 Properties of Determinants**

**2.5.1**

8.5.4

**2.5.3**

8.5.7

**2.5.5**

8.5.5

**2.5.7**

8.5.3

**2.5.9**

8.5.1

**2.5.11**

-5



**2.5.13**

$-5$

**2.5.15**

$5$

**2.5.17**

$80$

**2.5.19**

$-105$

**2.5.25**

$$\begin{aligned}\mathbf{A}\mathbf{A} &= \mathbf{I} \\ \det \mathbf{A} \cdot \det \mathbf{A} &= \det \mathbf{I} \\ (\det \mathbf{A})^2 &= 1 \\ \det \mathbf{A} &= \pm 1\end{aligned}$$

**2.5.27**

$$\begin{aligned}\begin{vmatrix} a & a+1 & a+2 \\ b & b+1 & b+2 \\ c & c+1 & c+2 \end{vmatrix} &= \begin{vmatrix} a & 1 & 2 \\ b & 1 & 2 \\ c & 1 & 2 \end{vmatrix} \\ &= \begin{vmatrix} a & 1 & 1 \\ b & 1 & 1 \\ c & 1 & 1 \end{vmatrix} \\ &= 0\end{aligned}$$

**2.5.29**

$$\begin{aligned}\begin{vmatrix} 1 & 1 & 5 \\ 4 & 3 & 6 \\ 0 & -1 & 1 \end{vmatrix} &= \begin{vmatrix} 1 & 1 & 5 \\ 0 & -1 & -14 \\ 0 & -1 & 1 \end{vmatrix} \\ &= - \begin{vmatrix} 1 & 1 & 5 \\ 0 & 1 & 14 \\ 0 & 0 & 15 \end{vmatrix} \\ &= -15\end{aligned}$$

**2.5.37**

$$\begin{aligned}
 \begin{vmatrix} 1 & 1 & 1 \\ a & b & c \\ a^2 & b^2 & c^2 \end{vmatrix} &= \begin{vmatrix} 1 & 1 & 1 \\ 0 & b-a & c-a \\ 0 & b^2-a^2 & c^2-a^2 \end{vmatrix} \\
 &= \begin{vmatrix} 1 & 1 & 1 \\ 0 & b-a & c-a \\ 0 & 0 & c^2-a^2-(b+a)(c-a) \end{vmatrix} \\
 &= (b-a)(c^2-a^2-(b+a)(c-a)) \\
 &= (b-a)(c^2-a^2-bc+ab-ac+a^2) \\
 &= (b-a)(c^2+ab-ac-bc) \\
 &= (b-a)(c-a)(c-b)
 \end{aligned}$$

**2.5.39**

$$\begin{aligned}
 a_{21}C_{11} + a_{22}C_{12} + a_{23}C_{13} &= (-1)(4) + (2)(5) + (1)(-6) \\
 &= 0 \\
 a_{13}C_{12} + a_{23}C_{22} + a_{33}C_{32} &= (2)(5) + (1)(-7) + (1)(-3) \\
 &= 0
 \end{aligned}$$

**2.5.41**

$$\begin{aligned}
 \mathbf{A} + \mathbf{B} &= \begin{pmatrix} 10 & 0 \\ 0 & -3 \end{pmatrix} \\
 \det(\mathbf{A} + \mathbf{B}) &= -30 \\
 \det \mathbf{A} &= 10 \\
 \det \mathbf{B} &= -31 \\
 -30 &\neq 10 - 31
 \end{aligned}$$

## **2.6 Inverse of a Matrix**

**2.6.3**

$$\begin{aligned}
 \det \mathbf{A} &= 9 \\
 \mathbf{A}^{-1} &= \frac{1}{9} \begin{pmatrix} 1 & 1 \\ -4 & 5 \end{pmatrix} \\
 &= \begin{pmatrix} \frac{1}{9} & \frac{1}{9} \\ -\frac{4}{9} & \frac{5}{9} \end{pmatrix}
 \end{aligned}$$

### 2.6.5

$$\det \mathbf{A} = 12$$

$$\begin{aligned}\mathbf{A}^{-1} &= \frac{1}{12} \begin{pmatrix} 2 & 0 \\ 3 & 6 \end{pmatrix} \\ &= \begin{pmatrix} \frac{1}{6} & 0 \\ \frac{1}{4} & \frac{1}{2} \end{pmatrix}\end{aligned}$$

### 2.6.7

$$\begin{aligned}\det \mathbf{A} &= (1) \begin{vmatrix} 4 & 4 \\ -1 & 1 \end{vmatrix} - (3) \begin{vmatrix} 2 & 4 \\ 1 & 1 \end{vmatrix} + (5) \begin{vmatrix} 2 & 4 \\ 1 & -1 \end{vmatrix} \\ &= 8 + 6 - 30 \\ &= -16\end{aligned}$$

$$\begin{aligned}\mathbf{A}^{-1} &= -\frac{1}{16} \begin{pmatrix} 8 & 2 & -6 \\ -8 & -4 & 4 \\ -8 & 6 & -2 \end{pmatrix}^T \\ &= \begin{pmatrix} -\frac{1}{2} & \frac{1}{2} & \frac{1}{2} \\ -\frac{1}{8} & \frac{1}{4} & -\frac{3}{8} \\ \frac{3}{8} & -\frac{1}{4} & \frac{1}{8} \end{pmatrix}\end{aligned}$$

### 2.6.15

$$\begin{aligned}&\left( \begin{array}{cc|cc} 6 & -2 & 1 & 0 \\ 0 & 4 & 0 & 1 \end{array} \right) \\ &\left( \begin{array}{cc|cc} 1 & -\frac{1}{3} & \frac{1}{6} & 0 \\ 0 & 1 & 0 & \frac{1}{4} \end{array} \right) \\ &\left( \begin{array}{cc|cc} 1 & 0 & \frac{1}{6} & \frac{1}{12} \\ 0 & 1 & 0 & \frac{1}{4} \end{array} \right)\end{aligned}$$

2.6.17

$$\begin{pmatrix} 1 & 3 & | & 1 & 0 \\ 5 & 3 & | & 0 & 1 \end{pmatrix}$$

$$\begin{pmatrix} 1 & 3 & | & 1 & 0 \\ 0 & -12 & | & -5 & 1 \end{pmatrix}$$

$$\begin{pmatrix} 1 & 3 & | & 1 & 0 \\ 0 & 1 & | & \frac{5}{12} & -\frac{1}{12} \end{pmatrix}$$

$$\begin{pmatrix} 1 & 0 & | & -\frac{1}{4} & \frac{1}{4} \\ 0 & 1 & | & \frac{5}{12} & -\frac{1}{12} \end{pmatrix}$$

2.6.27

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

$$= \begin{pmatrix} \frac{2}{3} & \frac{4}{3} \\ -\frac{1}{3} & \frac{5}{2} \end{pmatrix} \begin{pmatrix} \frac{1}{2} & -\frac{5}{2} \\ -\frac{1}{2} & \frac{3}{2} \end{pmatrix}$$

$$= \begin{pmatrix} -\frac{1}{3} & \frac{1}{3} \\ -\frac{17}{12} & \frac{55}{12} \end{pmatrix}$$

2.6.29

$$\begin{pmatrix} -2 & 3 \\ 3 & -4 \end{pmatrix}$$

2.6.31

$$\begin{pmatrix} 4 & -3 \\ x & -4 \end{pmatrix} = \frac{1}{3x-16} \begin{pmatrix} -4 & -x \\ 3 & 4 \end{pmatrix}^T$$

$$= \frac{1}{3x-16} \begin{pmatrix} -4 & 3 \\ -x & 4 \end{pmatrix}$$

$$-1 = \frac{1}{3x-16}$$

$$16 - 3x = 1$$

$$3x = 15$$

$$x = 5$$

**2.6.45**

$$\begin{aligned}\begin{pmatrix} 1 & 1 \\ 2 & -1 \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} &= \begin{pmatrix} 4 \\ 14 \end{pmatrix} \\ \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} &= -\frac{1}{3} \begin{pmatrix} -1 & -1 \\ -2 & 1 \end{pmatrix} \begin{pmatrix} 4 \\ 14 \end{pmatrix} \\ &= -\frac{1}{3} \begin{pmatrix} -18 \\ 6 \end{pmatrix} \\ &= \begin{pmatrix} 6 \\ -2 \end{pmatrix}\end{aligned}$$

**2.6.49**

$$\begin{aligned}\begin{pmatrix} 1 & 0 & 1 \\ 1 & 1 & 1 \\ 5 & -1 & 0 \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ x_3 \end{pmatrix} &= \begin{pmatrix} -4 \\ 0 \\ 6 \end{pmatrix} \\ \det \mathbf{A} &= \begin{vmatrix} 1 & 1 \\ -1 & 0 \end{vmatrix} + \begin{vmatrix} 1 & 1 \\ 5 & -1 \end{vmatrix} \\ &= 1 - 6 \\ &= -5 \\ \begin{pmatrix} x_1 \\ x_2 \\ x_3 \end{pmatrix} &= -\frac{1}{5} \begin{pmatrix} 1 & 5 & -6 \\ -1 & -5 & 1 \\ -1 & 0 & 1 \end{pmatrix}^T \begin{pmatrix} -4 \\ 0 \\ 6 \end{pmatrix} \\ &= -\frac{1}{5} \begin{pmatrix} 1 & -1 & -1 \\ 5 & -5 & 0 \\ -6 & 1 & 1 \end{pmatrix} \begin{pmatrix} -4 \\ 0 \\ 6 \end{pmatrix} \\ &= -\frac{1}{5} \begin{pmatrix} -10 \\ -20 \\ 30 \end{pmatrix} \\ &= \begin{pmatrix} 2 \\ 4 \\ -6 \end{pmatrix}\end{aligned}$$

**2.6.55**

$$\begin{aligned}\det \begin{pmatrix} 1 & 2 & -1 \\ 4 & -1 & 1 \\ 5 & 1 & -2 \end{pmatrix} &= (1) \begin{vmatrix} -1 & 1 \\ 1 & -2 \end{vmatrix} - (2) \begin{vmatrix} 4 & 1 \\ 5 & -2 \end{vmatrix} + (-1) \begin{vmatrix} 4 & -1 \\ 5 & 1 \end{vmatrix} \\ &= 1 + 26 - 9 \\ &= 18\end{aligned}$$

Only trivial solution