

# Euclidean Vector Space (1A)

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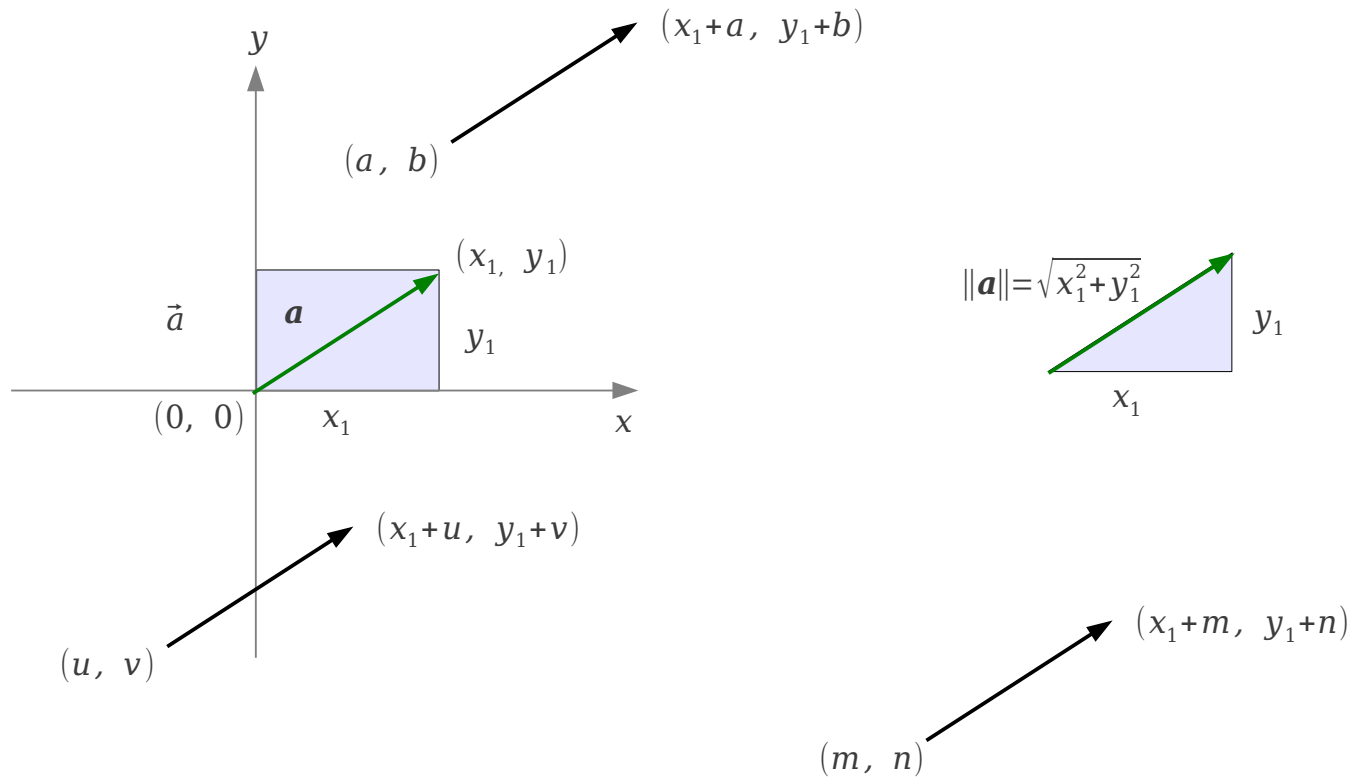
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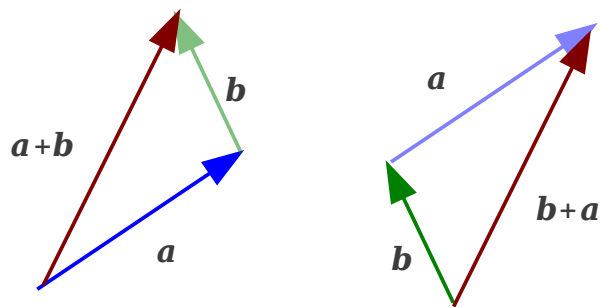
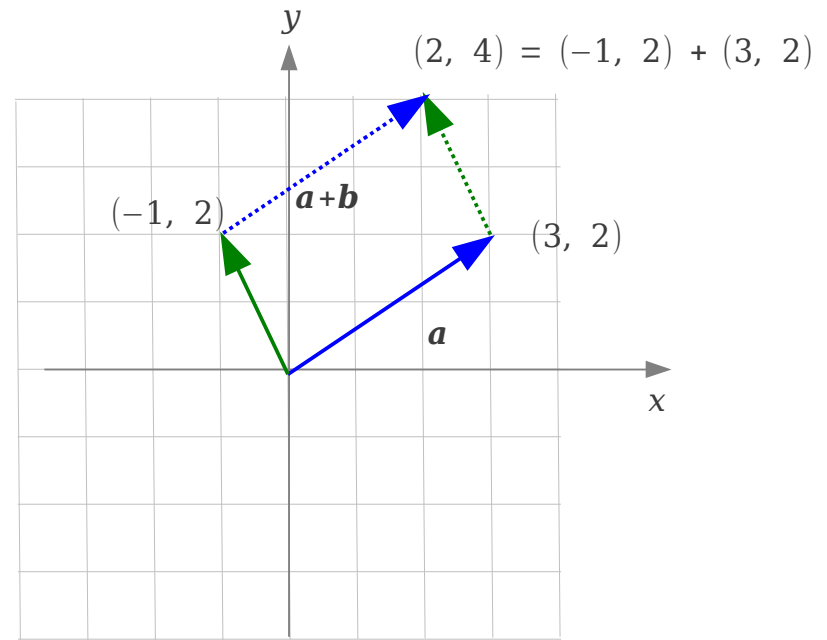
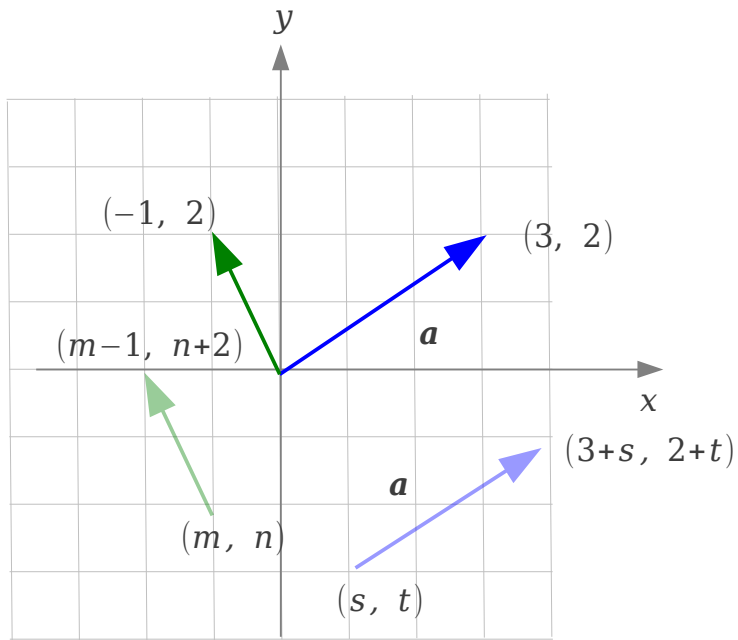
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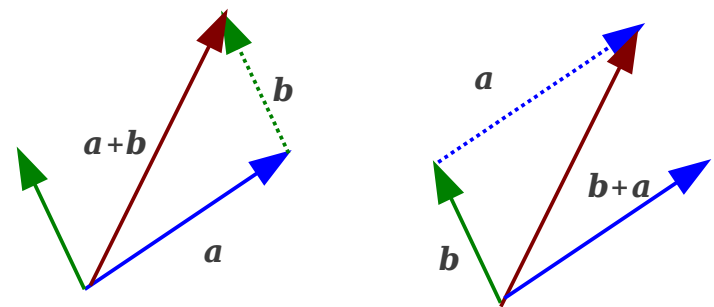
# Vectors



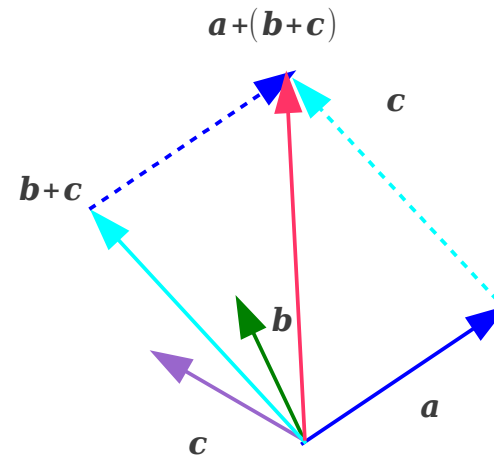
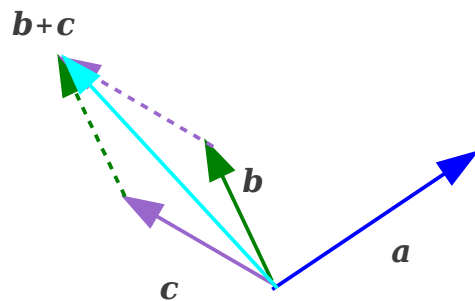
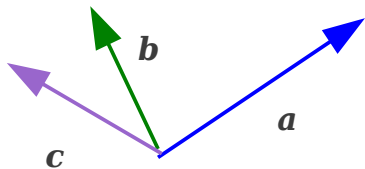
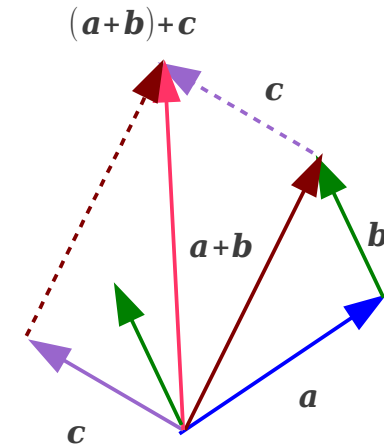
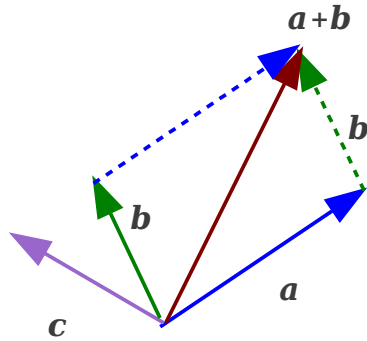
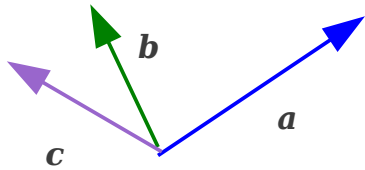
# Vector Addition



$$a+b = b+a$$

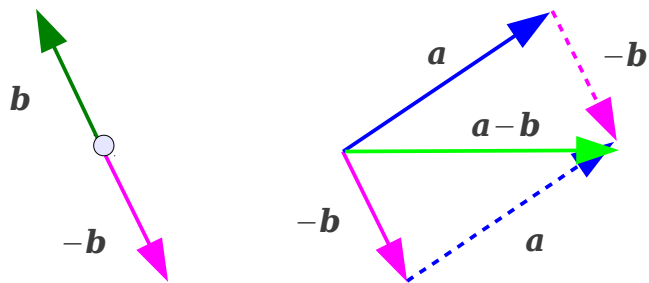
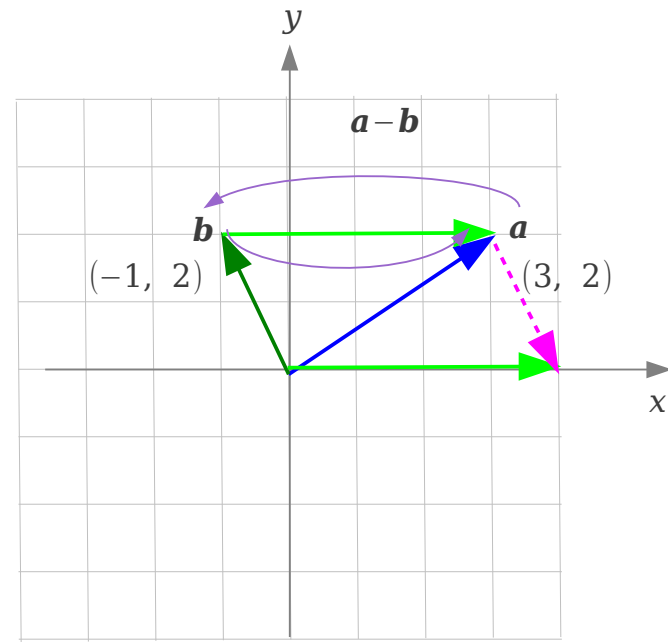
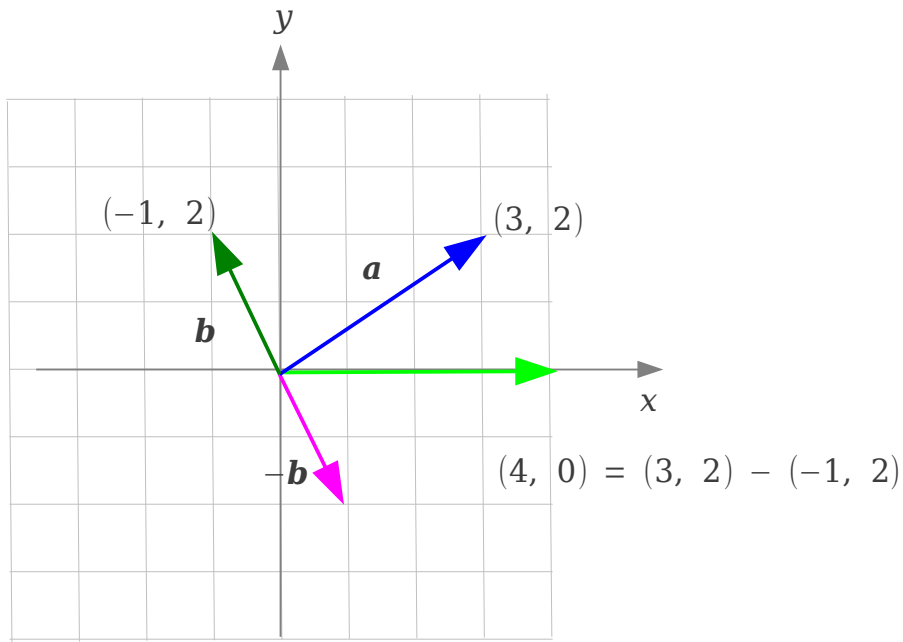


# Vector Addition



$$(a+b)+c = a+(b+c)$$

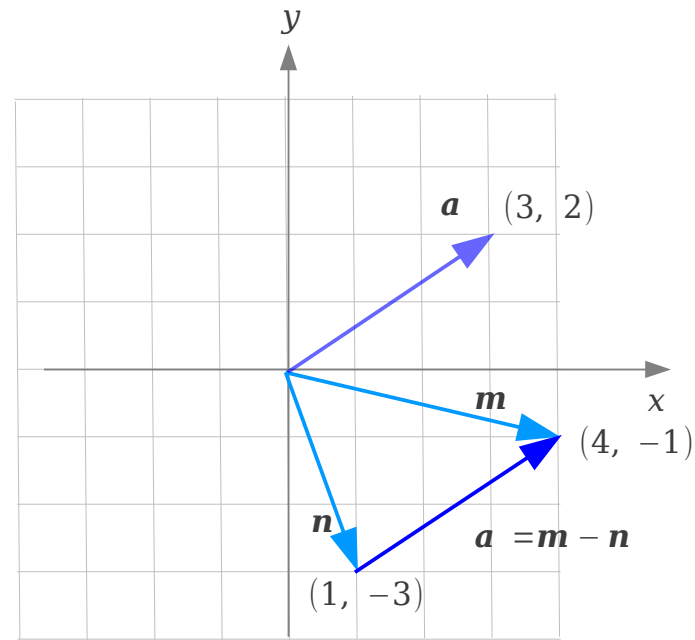
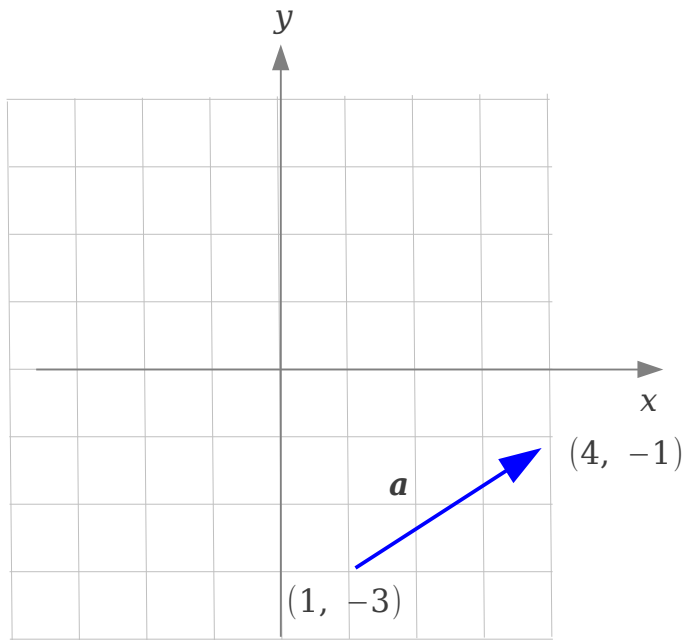
# Vector Subtraction



$a - b$

subtract  $a$  from  $b$   
 arrow from  $b$  to  $a$

# Component Form



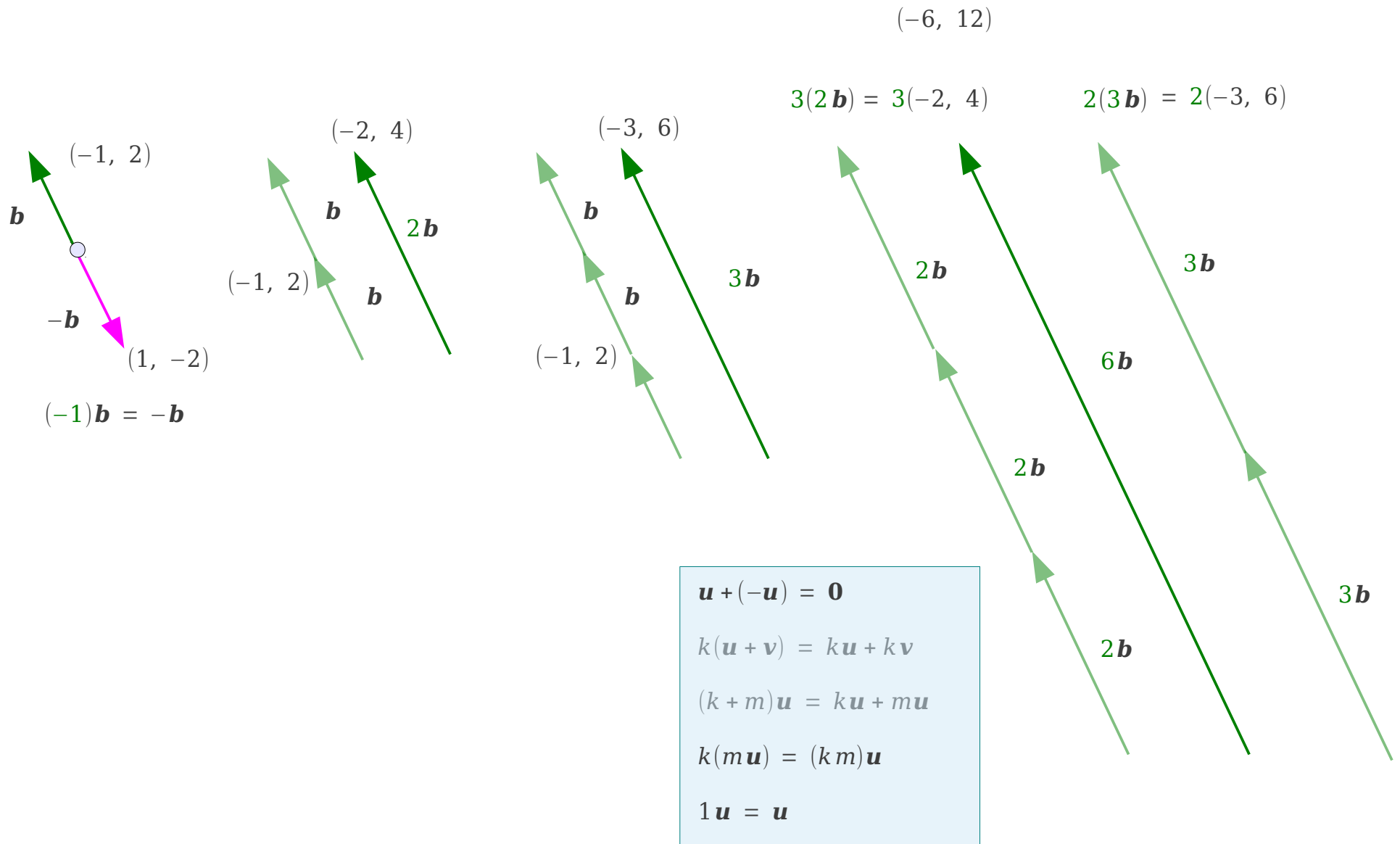
$$\mathbf{m} = (4, -1)$$

$$\mathbf{n} = (1, -3)$$

$$\mathbf{a} = \mathbf{m} - \mathbf{n} = (4, -1) - (1, -3) = (3, 2)$$

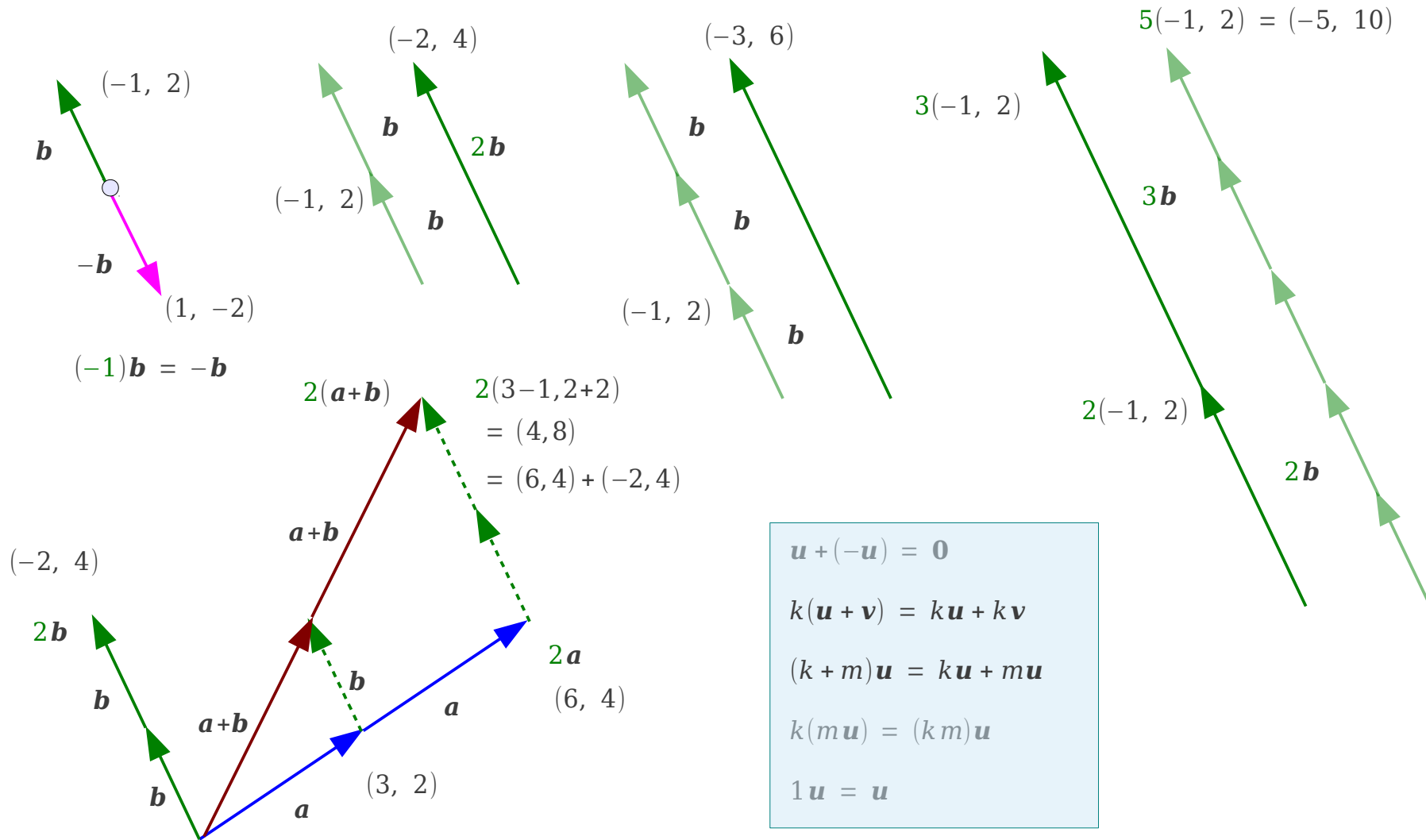
Finding the **Component Form** of a vector

# Scalar Multiplication (1)





# Scalar Multiplication (2)



# n-Space

Ordered 2-tuples  $(v_1, v_2)$   $v_1, v_2 \in R$

$R^2 \iff$  2-space  $\iff$  { all ordered 2-tuples  $(v_1, v_2)$  }

Ordered 3-tuples  $(v_1, v_2, v_3)$   $v_1, v_2, v_3 \in R$

$R^3 \iff$  3-space  $\iff$  { all ordered 3-tuples  $(v_1, v_2, v_3)$  }

Ordered n-tuples  $(v_1, v_2, \dots, v_n)$   $v_1, v_2, \dots, v_n \in R$

$R^n \iff$  n-space  $\iff$  { all ordered n-tuples  $(v_1, v_2, \dots, v_n)$  }

set



# Properties of Real Vector Spaces

$\mathbf{u}, \mathbf{v}, \mathbf{w}$  vectors in  $\mathbb{R}^n$

$k, m$  scalars

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

$$(\mathbf{u} + \mathbf{v}) + \mathbf{w} = \mathbf{u} + (\mathbf{v} + \mathbf{w})$$

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

$$\mathbf{u} + (-\mathbf{u}) = \mathbf{0}$$

$$k(\mathbf{u} + \mathbf{v}) = k\mathbf{u} + k\mathbf{v}$$

$$(k + m)\mathbf{u} = k\mathbf{u} + m\mathbf{u}$$

$$k(m\mathbf{u}) = (km)\mathbf{u}$$

$$1\mathbf{u} = \mathbf{u}$$

# Linear Combination

$\mathbf{w}, \mathbf{v}_1, \mathbf{v}_2, \dots, \mathbf{v}_r$  vectors in  $\mathbb{R}^n$   
 $k_1, k_2, \dots, k_r$  scalars

$\mathbf{w}$  is a **linear combination** of vectors  $\mathbf{v}_1, \mathbf{v}_2, \dots, \mathbf{v}_r$

$$\mathbf{w} = k_1 \mathbf{v}_1 + k_2 \mathbf{v}_2 + \dots + k_r \mathbf{v}_r$$

$$\begin{aligned} \begin{bmatrix} w_1 \\ w_2 \end{bmatrix} &= k_1 \begin{bmatrix} 1 \\ 0 \end{bmatrix} + k_2 \begin{bmatrix} 0 \\ 1 \end{bmatrix} \\ &= m_1 \begin{bmatrix} 1 \\ 1 \end{bmatrix} + m_2 \begin{bmatrix} 1 \\ -1 \end{bmatrix} \\ &= n_1 \begin{bmatrix} 1 \\ 1 \end{bmatrix} + n_2 \begin{bmatrix} 1 \\ -1 \end{bmatrix} + n_3 \begin{bmatrix} 0 \\ -1 \end{bmatrix} \end{aligned}$$

# Vector Magnitude

- Norm
  - Length
  - Magnitude
- $$\|\mathbf{v}\|$$

$$R^2 \quad \mathbf{v} = (v_1, v_2) \quad \|\mathbf{v}\| = \sqrt{v_1^2 + v_2^2} \geq 0$$

$$R^3 \quad \mathbf{v} = (v_1, v_2, v_3) \quad \|\mathbf{v}\| = \sqrt{v_1^2 + v_2^2 + v_3^2} \geq 0$$

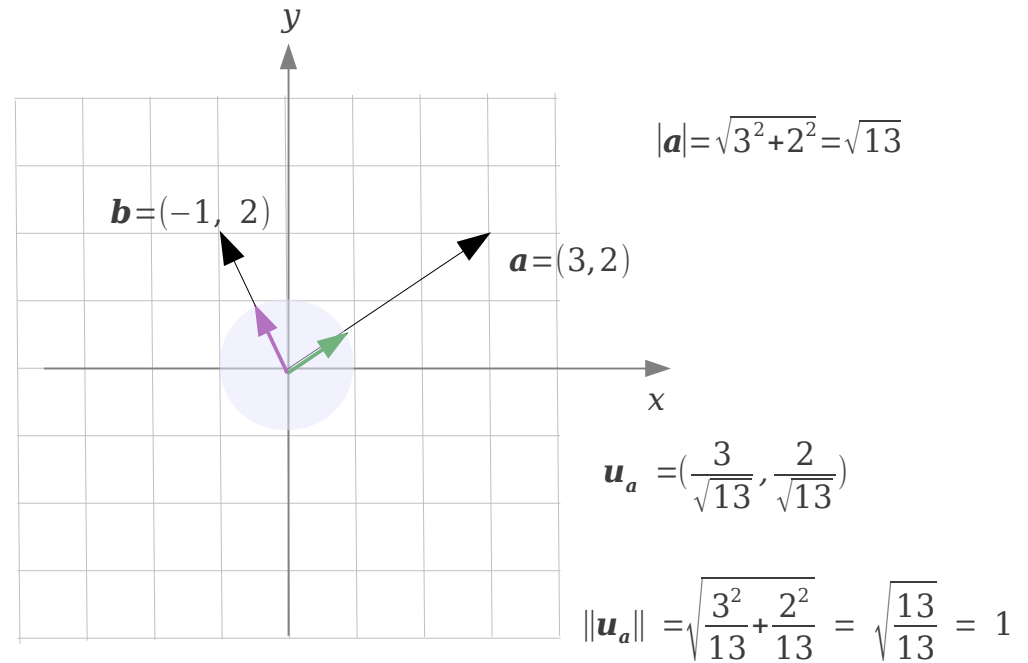
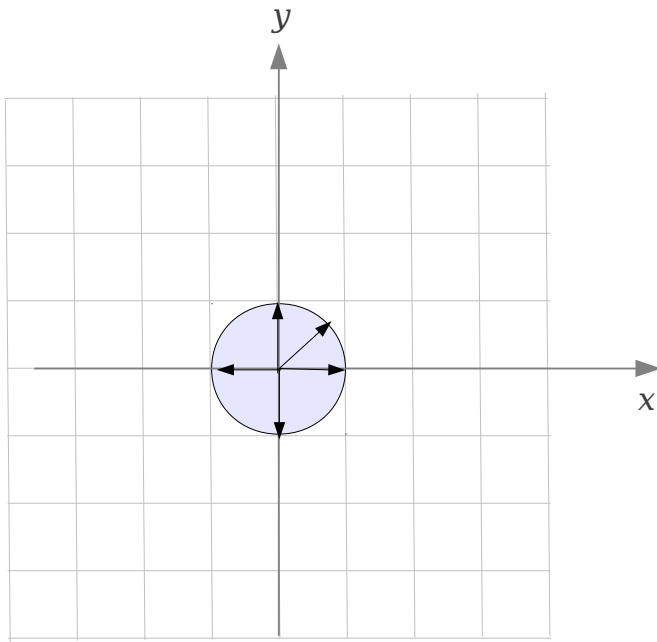
$$R^n \quad \mathbf{v} = (v_1, v_2, \dots, v_n) \quad \|\mathbf{v}\| = \sqrt{v_1^2 + v_2^2 + \dots + v_n^2} \geq 0$$

$$\|\mathbf{v}\| \geq 0$$

$$\|\mathbf{v}\| = 0 \quad \mathbf{v} = \mathbf{0}$$

$$\|k\mathbf{v}\| = |k| \|\mathbf{v}\| \geq 0$$

# Unit Vector



$$\mathbf{u} = \frac{\mathbf{v}}{\|\mathbf{v}\|}$$

$$\begin{aligned}\|\mathbf{u}\| &= \left\| \frac{\mathbf{v}}{\|\mathbf{v}\|} \right\| \\ &= \frac{\|\mathbf{v}\|}{\|\mathbf{v}\|} = 1\end{aligned}$$

$$\|\mathbf{v}\| \geq 0$$

# Standard Unit Vectors

$R^2$   $\leftrightarrow$  2-space  $\leftrightarrow$  { all ordered 2-tuples  $(v_1, v_2)$  }

$$\mathbf{i} = (1, 0) \qquad \mathbf{v} = (v_1, v_2) \qquad = v_1(1, 0)$$

$$\mathbf{j} = (0, 1) \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad + v_2(0, 1)$$

$R^3$   $\leftrightarrow$  3-space  $\leftrightarrow$  { all ordered 3-tuples  $(v_1, v_2, v_3)$  }

$$\mathbf{i} = (1, 0, 0) \qquad \mathbf{v} = (v_1, v_2, v_3) \qquad = v_1(1, 0, 0)$$

$$\mathbf{j} = (0, 1, 0) \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad + v_2(0, 1, 0)$$

$$\mathbf{k} = (0, 0, 1) \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad + v_3(0, 0, 1)$$

$R^n$   $\leftrightarrow$  n-space  $\leftrightarrow$  { all ordered n-tuples  $(v_1, v_2, \dots, v_n)$  }

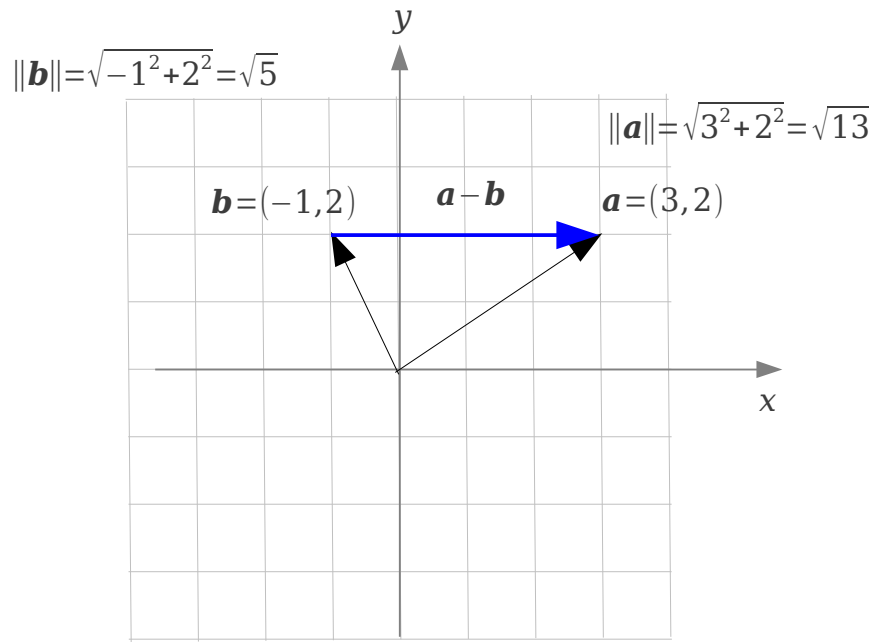
$$\mathbf{e}_1 = (1, 0, \dots, 0) \qquad \mathbf{v} = (v_1, v_2, \dots, v_n) \qquad = v_1(1, 0, \dots, 0)$$

$$\mathbf{e}_2 = (0, 1, \dots, 0) \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad + v_2(0, 1, \dots, 0)$$

$$\dots \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad + \dots$$

$$\mathbf{e}_n = (0, 0, \dots, 1) \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad + v_n(0, 0, \dots, 1)$$

# Distance between Vectors



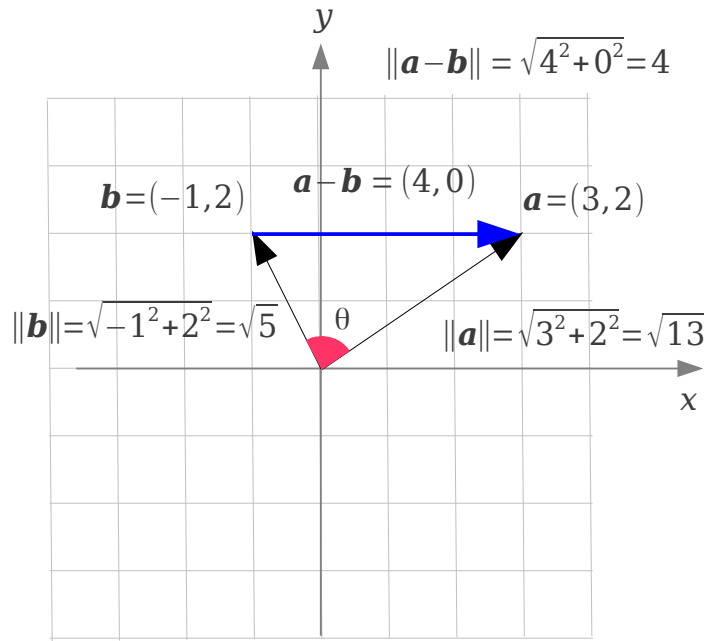
$$\begin{aligned} R^2 \quad d(\mathbf{a} - \mathbf{b}) &= \|\mathbf{a} - \mathbf{b}\| \\ &= \sqrt{(a_1 - b_1)^2 + (a_2 - b_2)^2} \geq 0 \end{aligned}$$

$$\begin{aligned} R^3 \quad d(\mathbf{a} - \mathbf{b}) &= \|\mathbf{a} - \mathbf{b}\| \\ &= \sqrt{(a_1 - b_1)^2 + (a_2 - b_2)^2 + (a_3 - b_3)^2} \geq 0 \end{aligned}$$

$$\begin{aligned} R^n \quad d(\mathbf{a} - \mathbf{b}) &= \|\mathbf{a} - \mathbf{b}\| \\ &= \sqrt{(a_1 - b_1)^2 + (a_2 - b_2)^2 + \cdots + (a_n - b_n)^2} \geq 0 \end{aligned}$$



# Law of Cosine



$$4^2 = \sqrt{13}^2 + \sqrt{5}^2 - 2\sqrt{13}\sqrt{5}\cos\theta$$

$$2 = 2\sqrt{13}\sqrt{5}\cos\theta \quad \cos\theta = \frac{1}{\sqrt{65}}$$

$$\mathbf{a} \cdot \mathbf{b} = 3 \cdot (-1) + 2 \cdot 2 = -3 + 4 = 1$$

$$R^2 \quad d(\mathbf{a} - \mathbf{b}) = \|\mathbf{a} - \mathbf{b}\| = \sqrt{(a_1 - b_1)^2 + (a_2 - b_2)^2} \geq 0$$

## Law of Cosine

$$\|\mathbf{a} - \mathbf{b}\|^2 = \|\mathbf{a}\|^2 + \|\mathbf{b}\|^2 - 2\|\mathbf{a}\|\|\mathbf{b}\|\cos\theta$$

$$\begin{aligned} \mathbf{a} - \mathbf{b} \\ = (a_1 - b_1, a_2 - b_2) \end{aligned}$$

$$\begin{aligned} \mathbf{a} &= (a_1, a_2) \\ \mathbf{b} &= (b_1, b_2) \end{aligned}$$

$$(a_1 - b_1)^2 + (a_2 - b_2)^2$$

$$a_1^2 + a_2^2$$

$$b_1^2 + b_2^2$$

$$-2(a_1 b_1 + a_2 b_2)$$

-2

$$a_1^2 + a_2^2$$

$$b_1^2 + b_2^2$$

$$\sqrt{a_1^2 + a_2^2}$$

$$\sqrt{b_1^2 + b_2^2}$$

cos $\theta$

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

# Dot Product

Dot Product  
Euclidean Inner Product

$\mathbf{a}, \mathbf{b}$  Vectors in  $R^n$   
 $\theta$  Angle between  $\mathbf{a}, \mathbf{b}$

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



$$\mathbf{a} \cdot \mathbf{a} = \|\mathbf{a}\| \|\mathbf{a}\| \cos 0^\circ$$



$$\|\mathbf{a}\| = \sqrt{\mathbf{a} \cdot \mathbf{a}}$$

$$\begin{aligned} R^2 \quad \mathbf{a} \cdot \mathbf{b} &= \|\mathbf{a}\| \|\mathbf{b}\| \cos \theta \\ &= a_1 b_1 + a_2 b_2 \end{aligned}$$

$$\begin{aligned} R^3 \quad \mathbf{a} \cdot \mathbf{b} &= \|\mathbf{a}\| \|\mathbf{b}\| \cos \theta \\ &= a_1 b_1 + a_2 b_2 + a_3 b_3 \end{aligned}$$

$$\begin{aligned} R^n \quad \mathbf{a} \cdot \mathbf{b} &= \|\mathbf{a}\| \|\mathbf{b}\| \cos \theta \\ &= a_1 b_1 + a_2 b_2 + \cdots + a_n b_n \end{aligned}$$

# Properties of Dot Products

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

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

$$k(\mathbf{a} \cdot \mathbf{b}) = (k\mathbf{a}) \cdot \mathbf{b}$$

$$\mathbf{a} \cdot \mathbf{a} \geq 0 \quad \mathbf{a} \cdot \mathbf{a} = 0 \iff \mathbf{a} = \mathbf{0}$$

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

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

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

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

$$k(\mathbf{a} \cdot \mathbf{b}) = \mathbf{a} \cdot (k\mathbf{b})$$

$$\begin{aligned} \mathbf{a} \cdot \mathbf{b} &= \|\mathbf{a}\| \|\mathbf{b}\| \cos \theta \\ &= a_1 b_1 + a_2 b_2 + \cdots + a_n b_n \end{aligned}$$

# Cauchy-Schwarz Inequality

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

$$-1 \leq \cos\theta \leq +1$$

$$-1 \leq \frac{\mathbf{a} \cdot \mathbf{b}}{\|\mathbf{a}\| \|\mathbf{b}\|} \leq +1$$

$$\frac{|\mathbf{a} \cdot \mathbf{b}|}{\|\mathbf{a}\| \|\mathbf{b}\|} \leq 1$$

$$|\mathbf{a} \cdot \mathbf{b}| \leq \|\mathbf{a}\| \|\mathbf{b}\|$$

$$a_1 b_1 + a_2 b_2 + \cdots + a_n b_n \leq \sqrt{a_1^2 + a_2^2 + \cdots + a_n^2} \sqrt{b_1^2 + b_2^2 + \cdots + b_n^2}$$

$$\begin{aligned} \mathbf{a} \cdot \mathbf{b} &= \|\mathbf{a}\| \|\mathbf{b}\| \cos\theta \\ &= a_1 b_1 + a_2 b_2 + \cdots + a_n b_n \end{aligned}$$

$$\mathbf{a} = (a_1, a_2, \cdots, a_n)$$

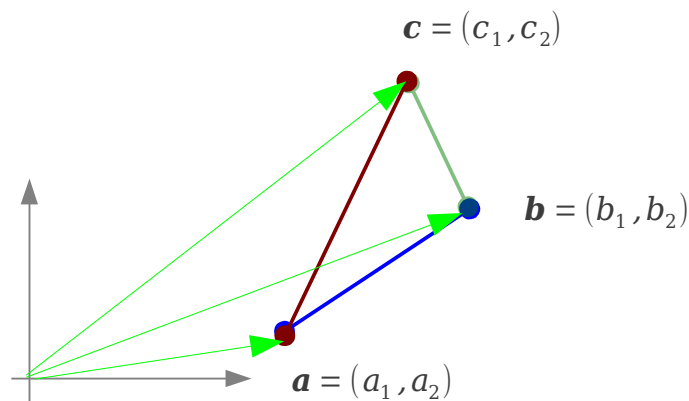
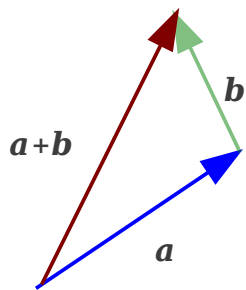
$$\mathbf{b} = (b_1, b_2, \cdots, b_n)$$

$$\mathbf{a} \cdot \mathbf{b} = a_1 b_1 + a_2 b_2 + \cdots + a_n b_n$$

$$\|\mathbf{a}\| = \sqrt{a_1^2 + a_2^2 + \cdots + a_n^2}$$

$$\|\mathbf{b}\| = \sqrt{b_1^2 + b_2^2 + \cdots + b_n^2}$$

# Triangular Inequalities



$$\|\mathbf{a} + \mathbf{b}\| \leq \|\mathbf{a}\| + \|\mathbf{b}\|$$

$$\begin{aligned} \|\mathbf{a} + \mathbf{b}\|^2 &= (\mathbf{a} + \mathbf{b}) \cdot (\mathbf{a} + \mathbf{b}) \\ &= (\mathbf{a} \cdot \mathbf{a}) + 2(\mathbf{a} \cdot \mathbf{b}) + (\mathbf{b} \cdot \mathbf{b}) \\ &\leq \|\mathbf{a}\|^2 + 2|\mathbf{a} \cdot \mathbf{b}| + \|\mathbf{b}\|^2 \\ &\leq \|\mathbf{a}\|^2 + 2\|\mathbf{a}\| \|\mathbf{b}\| + \|\mathbf{b}\|^2 \\ &\leq (\|\mathbf{a}\| + \|\mathbf{b}\|)^2 \end{aligned}$$

$$\begin{aligned} \mathbf{a} \cdot \mathbf{a} &= \|\mathbf{a}\|^2 \\ \mathbf{b} \cdot \mathbf{b} &= \|\mathbf{b}\|^2 \\ \mathbf{a} \cdot \mathbf{b} &\leq |\mathbf{a} \cdot \mathbf{b}| \\ |\mathbf{a} \cdot \mathbf{b}| &\leq \|\mathbf{a}\| \|\mathbf{b}\| \end{aligned}$$

$$d(\mathbf{a}, \mathbf{b}) \leq d(\mathbf{a}, \mathbf{c}) + d(\mathbf{c}, \mathbf{b})$$

$$\begin{aligned} d(\mathbf{a}, \mathbf{b}) &= \|\mathbf{a} - \mathbf{b}\| \\ &= \|\mathbf{a} - \mathbf{c} + \mathbf{c} - \mathbf{b}\| \\ &= \|(\mathbf{a} - \mathbf{c}) + (\mathbf{c} - \mathbf{b})\| \\ &\leq \|\mathbf{a} - \mathbf{c}\| + \|\mathbf{c} - \mathbf{b}\| \\ &\leq d(\mathbf{a}, \mathbf{c}) + d(\mathbf{c}, \mathbf{b}) \end{aligned}$$

# Orthogonality

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

$$-1 \leq \cos\theta \leq +1$$

$$-1 \leq \frac{\mathbf{a} \cdot \mathbf{b}}{\|\mathbf{a}\| \|\mathbf{b}\|} \leq +1$$

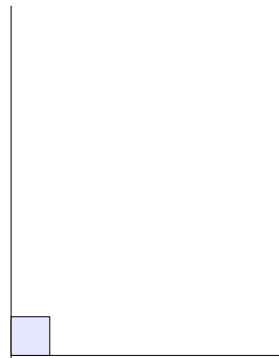
$$\frac{|\mathbf{a} \cdot \mathbf{b}|}{\|\mathbf{a}\| \|\mathbf{b}\|} \leq 1$$

$$\cos 90^\circ = 0$$

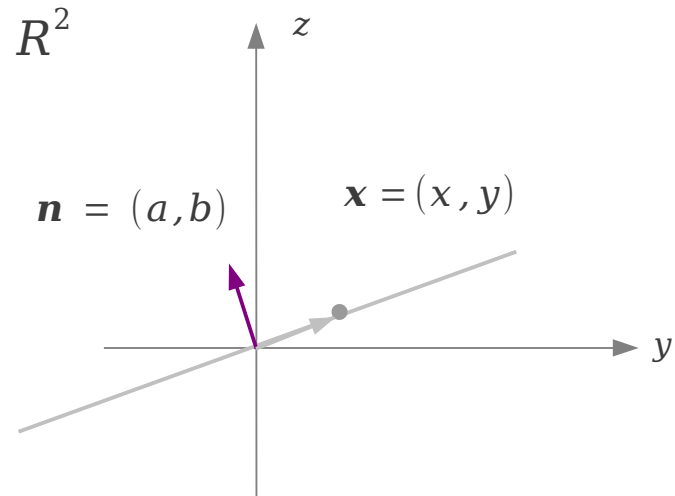
$$\frac{\mathbf{a} \cdot \mathbf{b}}{\|\mathbf{a}\| \|\mathbf{b}\|} = 0$$

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

$$\begin{aligned} R^n \quad \mathbf{a} \cdot \mathbf{b} &= \|\mathbf{a}\| \|\mathbf{b}\| \cos\theta \\ &= a_1 b_1 + a_2 b_2 + \cdots + a_n b_n \end{aligned}$$

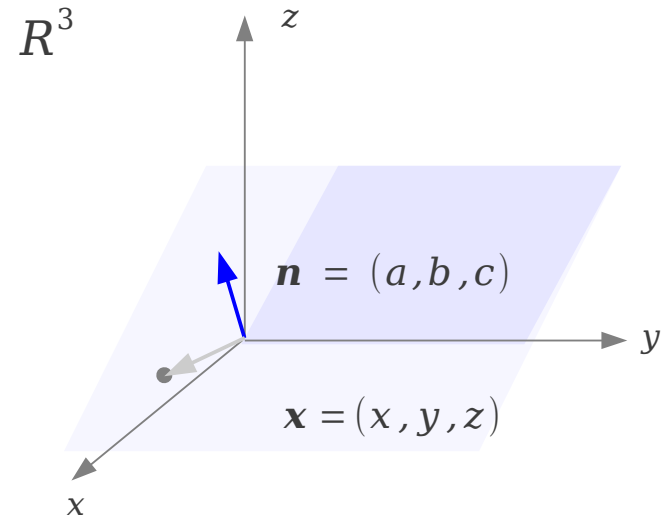


# Point-Normal Equation (1)



$$\mathbf{n} \cdot \mathbf{x} = 0$$

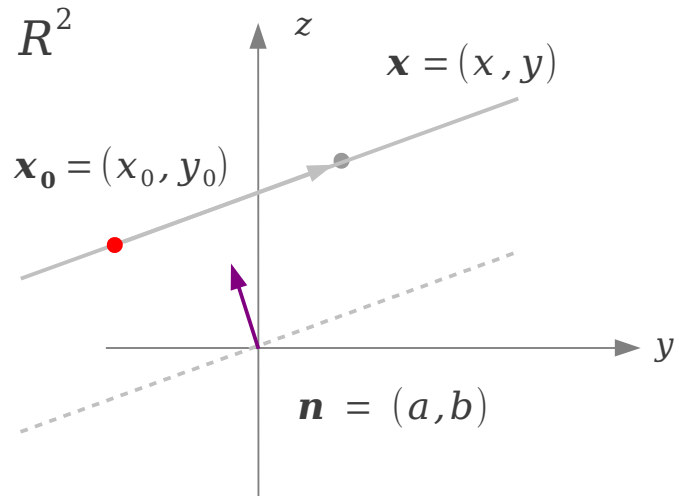
$$ax + by = 0$$



$$\mathbf{n} \cdot \mathbf{x} = 0$$

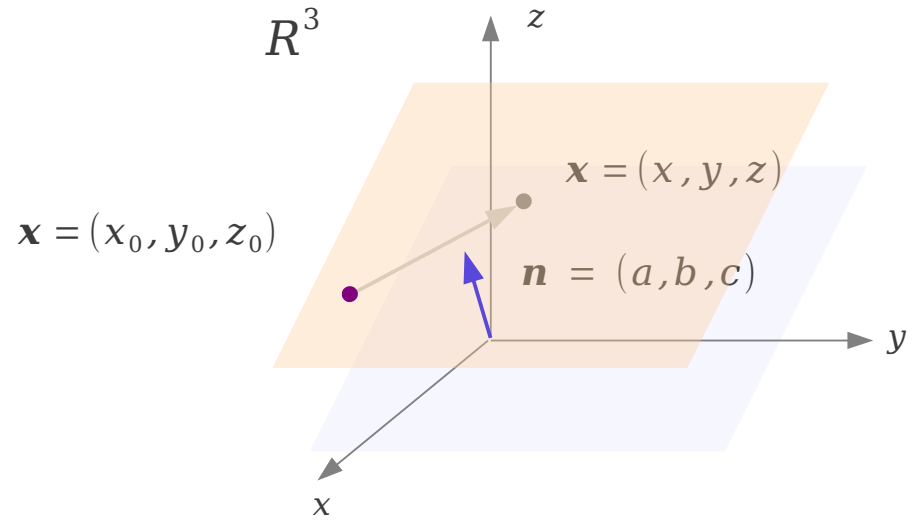
$$ax + by + cz = 0$$

# Point-Normal Equation (2)



$$\mathbf{n} \cdot (\mathbf{x} - \mathbf{x}_0) = 0$$

$$a(x - x_0) + b(y - y_0) = 0$$

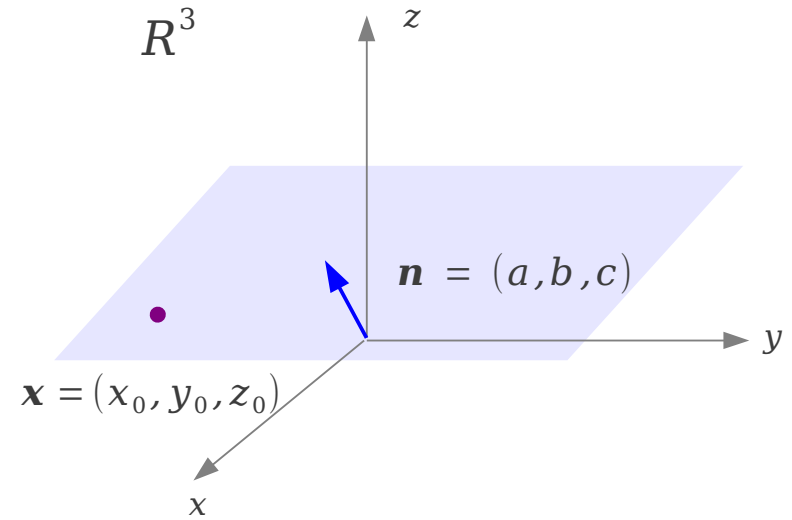
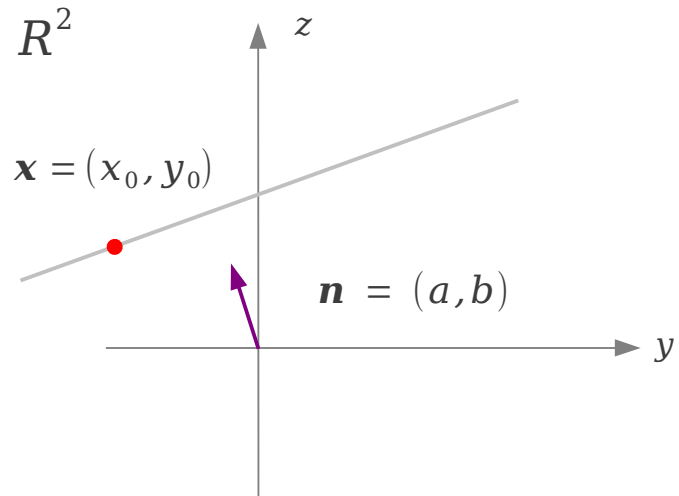


$$\mathbf{n} \cdot (\mathbf{x} - \mathbf{x}_0) = 0$$

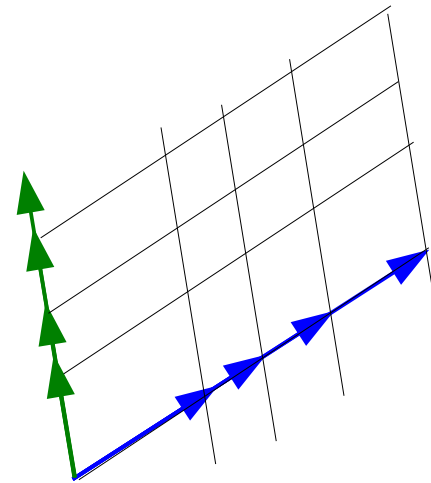
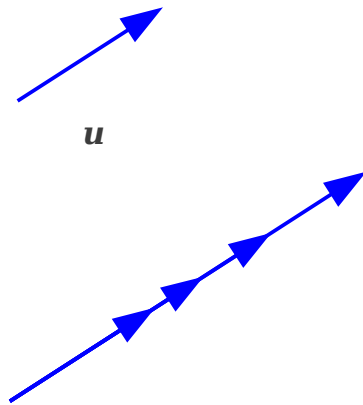
$$a(x - x_0) + b(y - y_0) + c(z - z_0) = 0$$



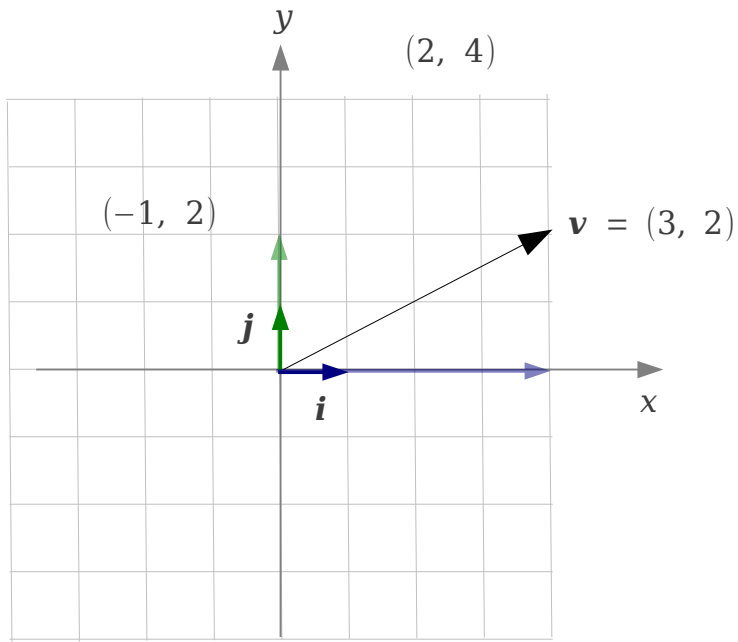
# Point-Normal Equation



# Vector Addition



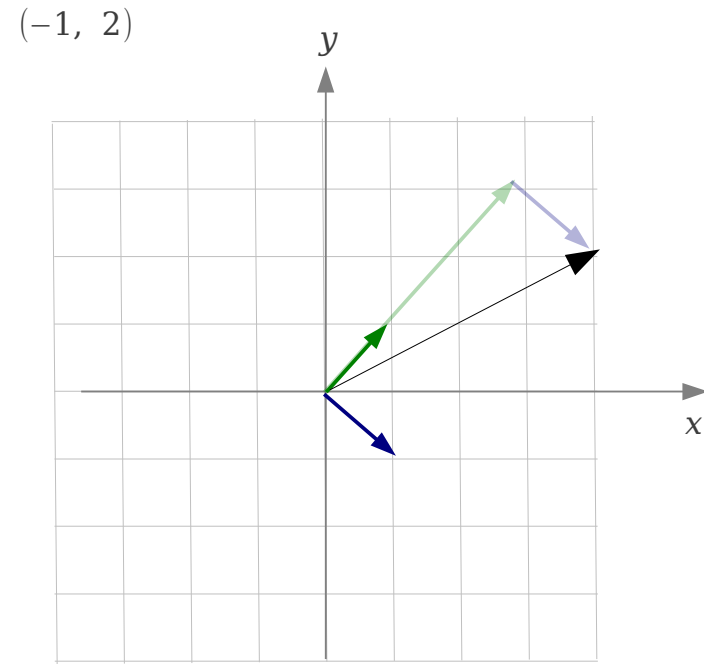
# Basis



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

$$a \begin{bmatrix} 1 \\ 0 \end{bmatrix} + b \begin{bmatrix} 0 \\ 1 \end{bmatrix} = \mathbf{0} \implies a = b = 0$$

*basis*



$$a \begin{bmatrix} 1 \\ 1 \end{bmatrix} + b \begin{bmatrix} 1 \\ -1 \end{bmatrix} = \mathbf{0} \implies a = b = 0$$

*basis*

# Cross Product (1)

## Determinant of order 3

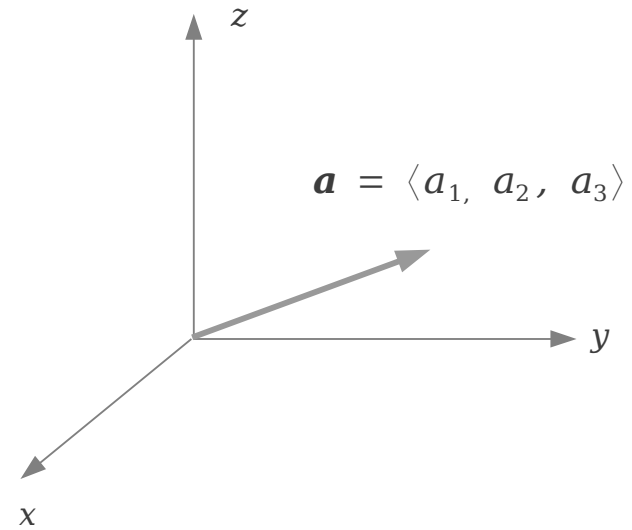
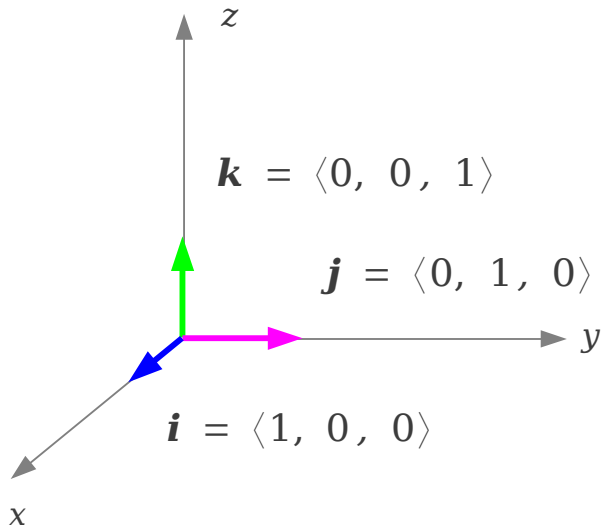
$$\mathbf{a} = a_1\mathbf{i} + a_2\mathbf{j} + a_3\mathbf{k} = \langle a_1, a_2, a_3 \rangle$$

$$\mathbf{b} = b_1\mathbf{i} + b_2\mathbf{j} + b_3\mathbf{k} = \langle b_1, b_2, b_3 \rangle$$

$$\mathbf{a} \times \mathbf{b} = \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \end{vmatrix} = \mathbf{i} \begin{vmatrix} a_2 & a_3 \\ b_2 & b_3 \end{vmatrix} - \mathbf{j} \begin{vmatrix} a_1 & a_3 \\ b_1 & b_3 \end{vmatrix} + \mathbf{k} \begin{vmatrix} a_1 & a_2 \\ b_1 & b_2 \end{vmatrix}$$

$$= (a_2b_3 - a_3b_2)\mathbf{i} - (a_1b_3 - a_3b_1)\mathbf{j} + (a_1b_2 - a_2b_1)\mathbf{k}$$

# Cross Product (2)



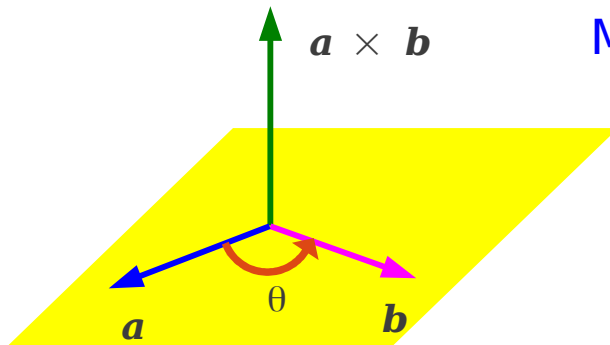
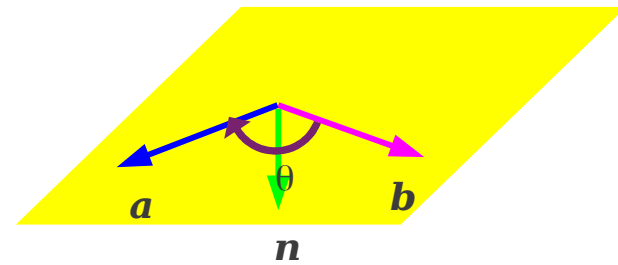
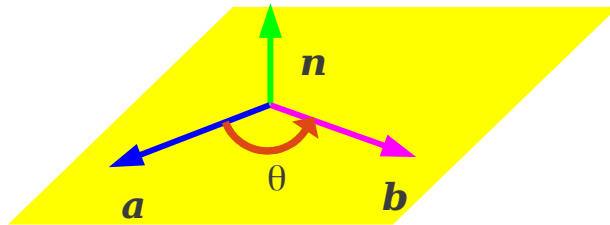
$$\begin{aligned}
 \mathbf{i} \times \mathbf{j} &= \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{vmatrix} = \mathbf{k} \quad \leftarrow \text{normal to } \mathbf{i} \ \& \ \mathbf{j} \quad \rightarrow \quad \mathbf{j} \times \mathbf{i} = \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ 0 & 1 & 0 \\ 1 & 0 & 0 \end{vmatrix} = -\mathbf{k} \\
 \mathbf{j} \times \mathbf{k} &= \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{vmatrix} = \mathbf{i} \quad \leftarrow \text{normal to } \mathbf{j} \ \& \ \mathbf{k} \quad \rightarrow \quad \mathbf{k} \times \mathbf{j} = \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{vmatrix} = -\mathbf{i} \\
 \mathbf{k} \times \mathbf{i} &= \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{vmatrix} = \mathbf{j} \quad \leftarrow \text{normal to } \mathbf{k} \ \& \ \mathbf{i} \quad \rightarrow \quad \mathbf{i} \times \mathbf{k} = \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ 1 & 0 & 0 \\ 0 & 0 & 1 \end{vmatrix} = -\mathbf{j}
 \end{aligned}$$

# Right Hand Rule

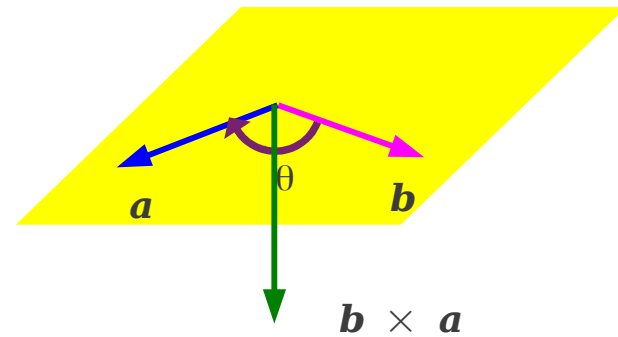
$$\mathbf{a} \times \mathbf{b} = \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \end{vmatrix}$$

$$\mathbf{b} \times \mathbf{a} = \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ b_1 & b_2 & b_3 \\ a_1 & a_2 & a_3 \end{vmatrix}$$

Normal direction  $n$



Magnitude =  $\|\mathbf{a} \times \mathbf{b}\| = \|\mathbf{a}\| \|\mathbf{b}\| \sin \theta$



# Line Equations (1)

## Vector Equation

Parameter

Direction Vector

$$\mathbf{r} = \mathbf{r}_2 + t\mathbf{a}$$

$$\mathbf{r}_2 = \langle x_2, y_2, z_2 \rangle$$

$$\mathbf{a} = \langle a_1, a_2, a_3 \rangle$$

## Parametric Equation

Component

$$x = x_2 + ta_1$$

$$y = y_2 + ta_2$$

$$z = z_2 + ta_3$$

$$ta_1 = x - x_2$$

$$ta_2 = y - y_2$$

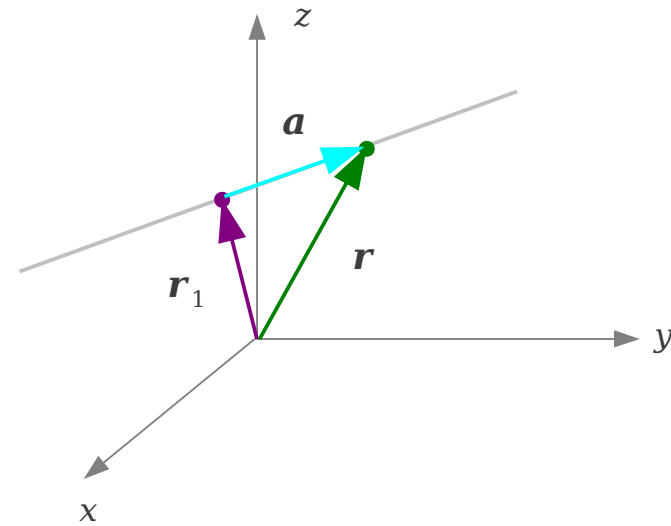
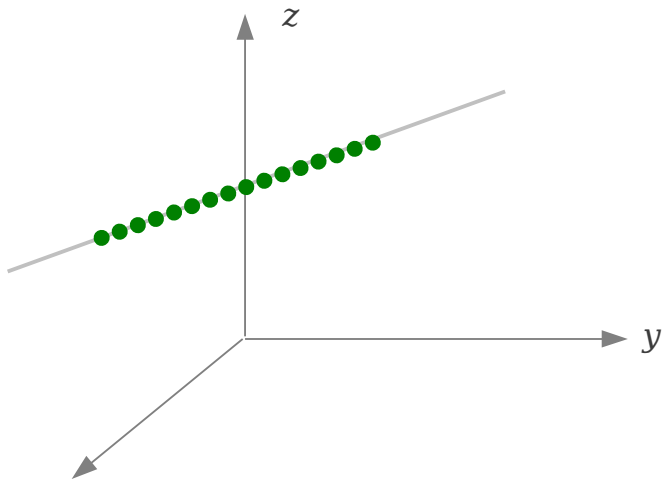
$$ta_3 = z - z_2$$

## Symmetric Equation

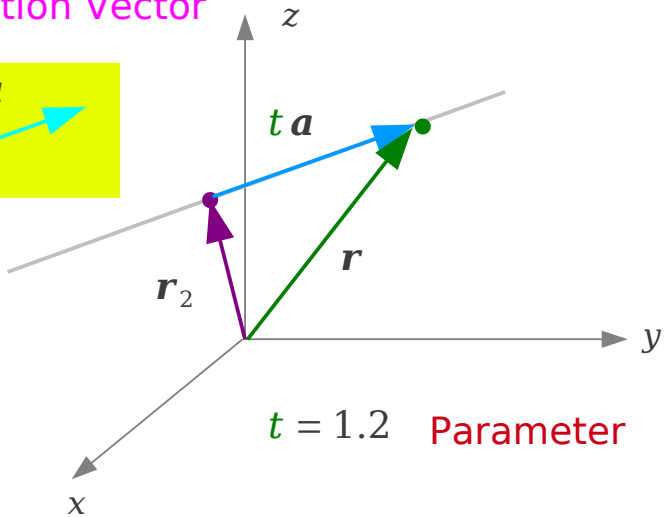
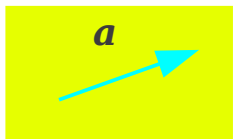
Elimination of parameter

$$t = \frac{x - x_2}{a_1} = \frac{y - y_2}{a_2} = \frac{z - z_2}{a_3}$$

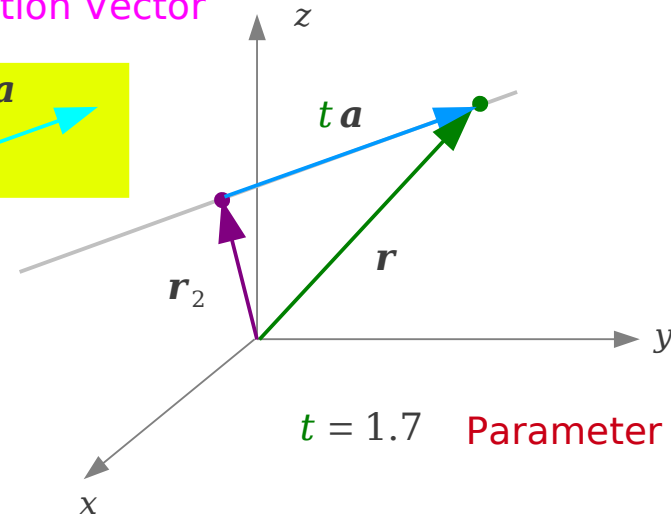
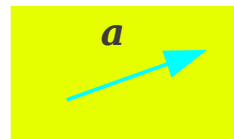
# Line Equations (2)



Direction Vector

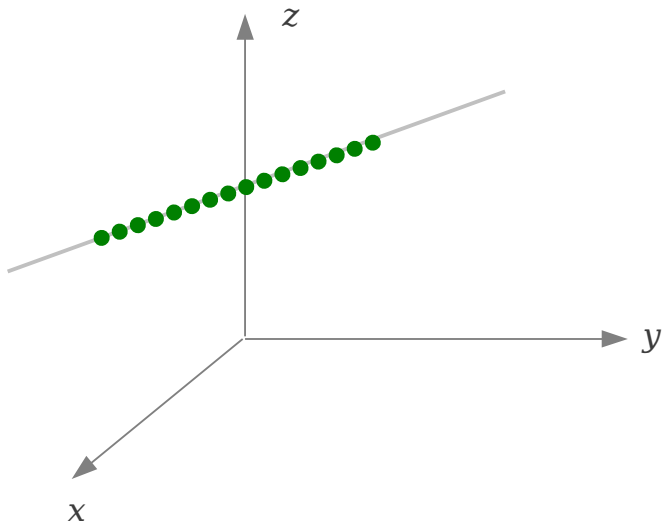


Direction Vector

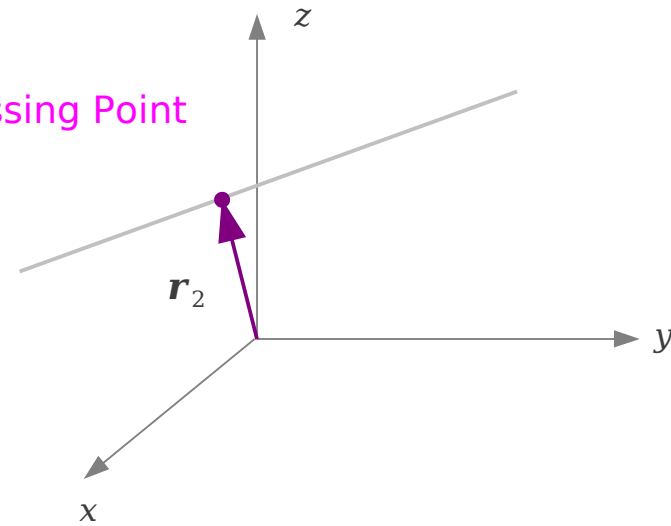




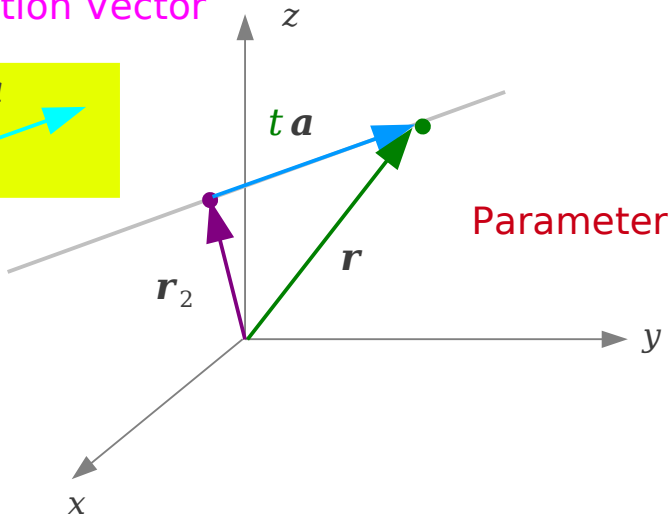
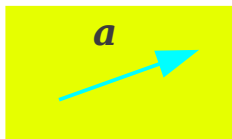
# Line Equations (3)



A Passing Point



Direction Vector



$$\mathbf{r} = \mathbf{r}_2 + t\mathbf{a}$$

$$\mathbf{r}_2 = \langle x_2, y_2, z_2 \rangle$$

$$\mathbf{a} = \langle a_1, a_2, a_3 \rangle$$

# Plane Equations (1)

Vector equation

$$\mathbf{n} \cdot (\mathbf{r} - \mathbf{r}_1) = 0$$

Normal Vector

$$\mathbf{r} = \langle x, y, z \rangle$$

$$\mathbf{r}_1 = \langle x_1, y_1, z_1 \rangle$$

$$\mathbf{n} = \langle a, b, c \rangle$$

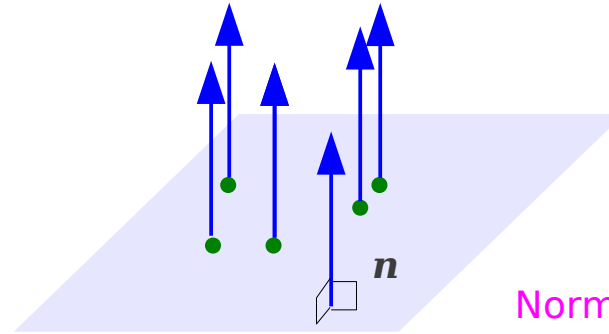
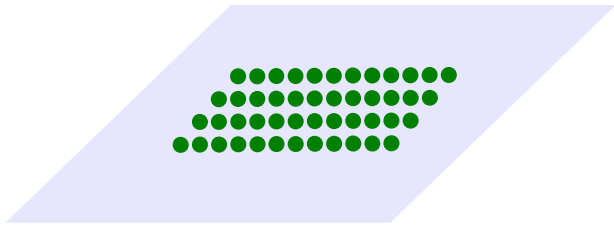
$$\mathbf{r} - \mathbf{r}_1 = \langle x - x_1, y - y_1, z - z_1 \rangle$$

$$\mathbf{n} = \langle a, b, c \rangle$$

Cartesian equation

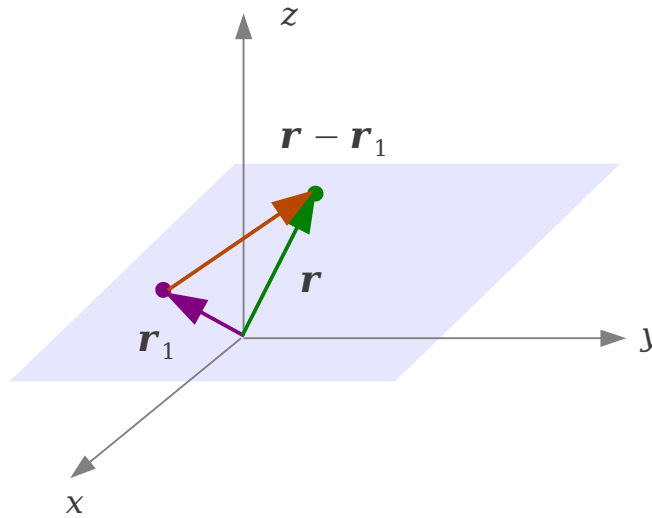
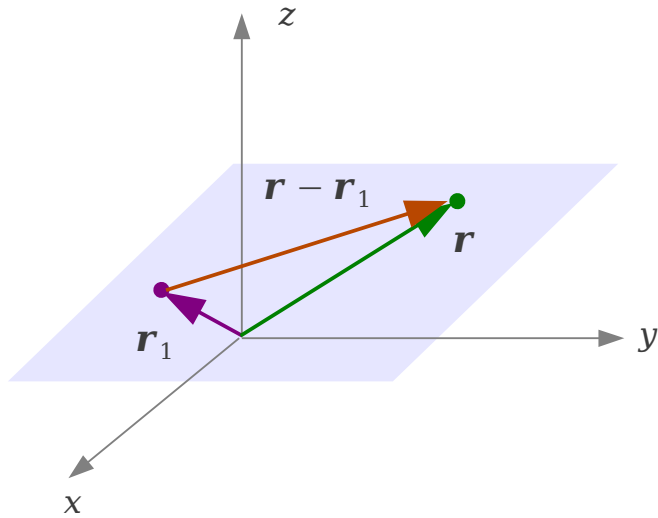
$$a(x - x_1) + b(y - y_1) + c(z - z_1) = 0$$

# Plane Equations (2)

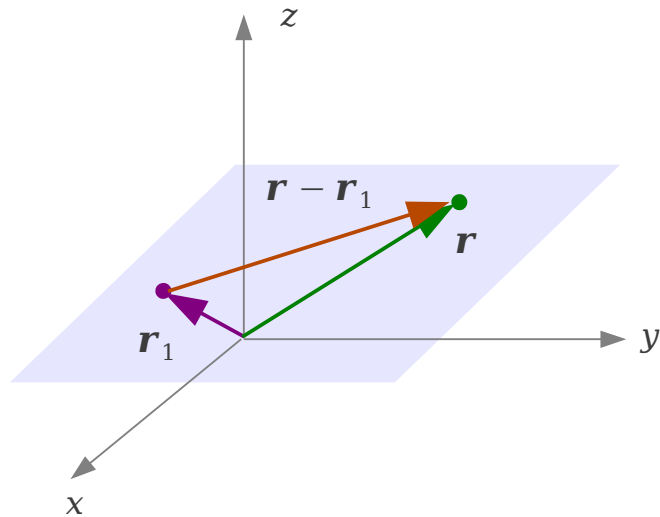
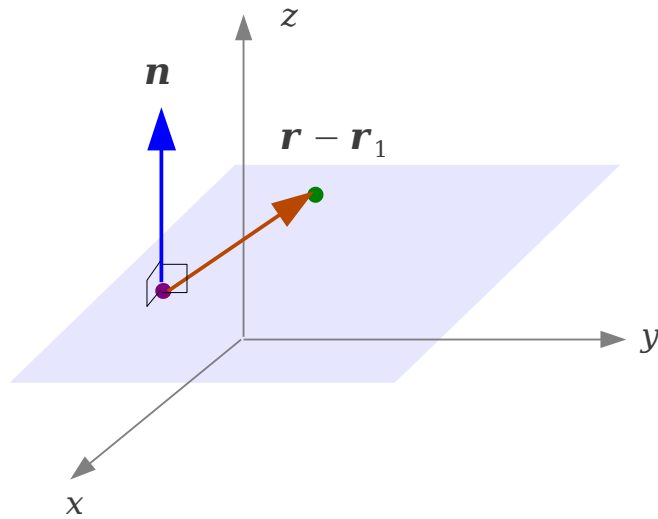
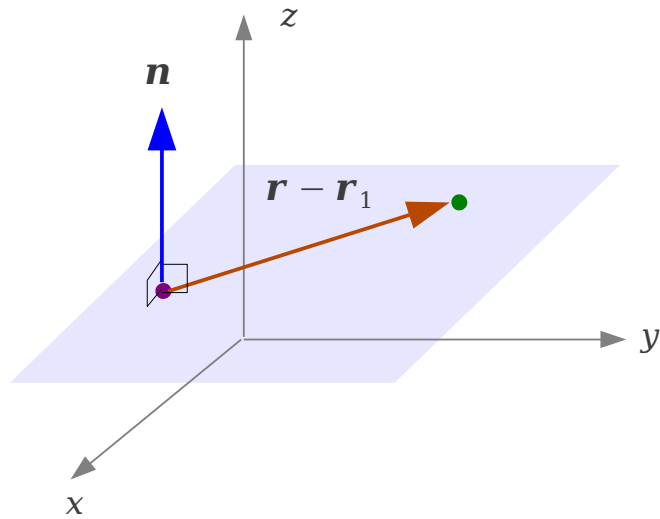


Normal Vector

No Parameter



# Plane Equations (3)



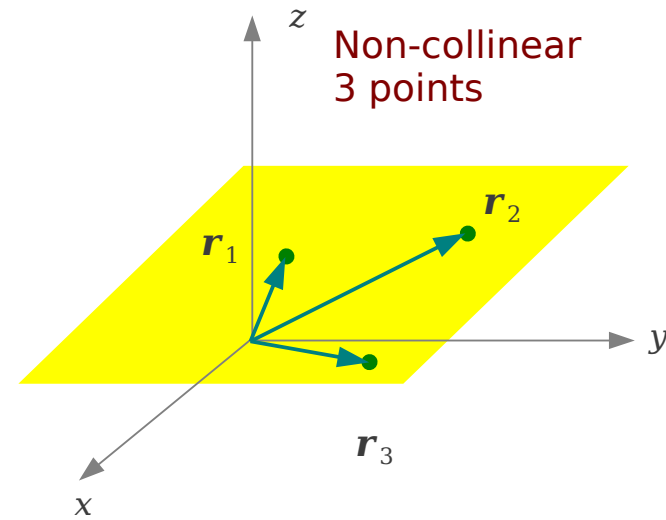
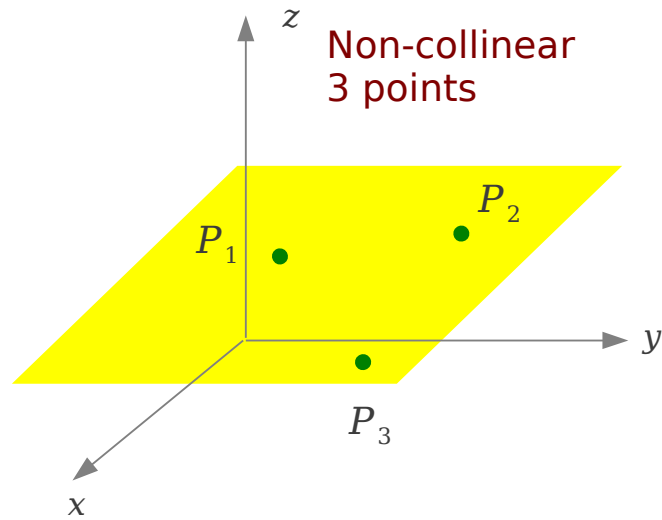
$$\mathbf{n} \cdot (\mathbf{r} - \mathbf{r}_1) = 0$$

$$\mathbf{r} = \langle x, y, z \rangle$$

$$\mathbf{r}_1 = \langle x_1, y_1, z_1 \rangle$$

$$\mathbf{n} = \langle a, b, c \rangle$$

# Normal Vector & 3 Points



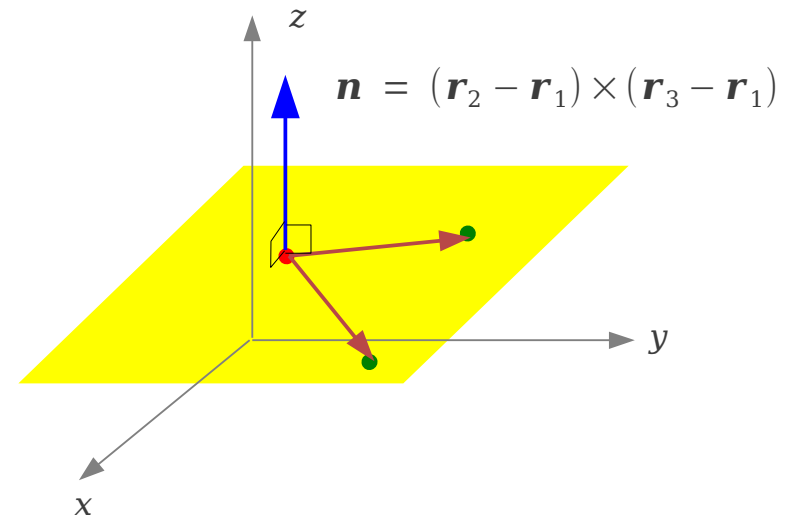
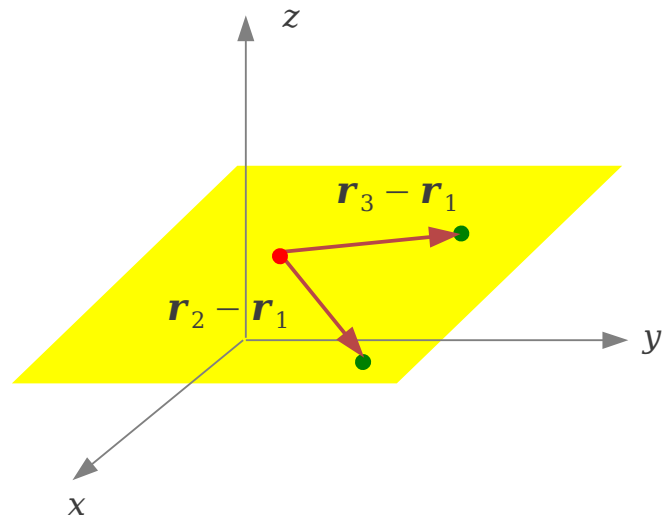
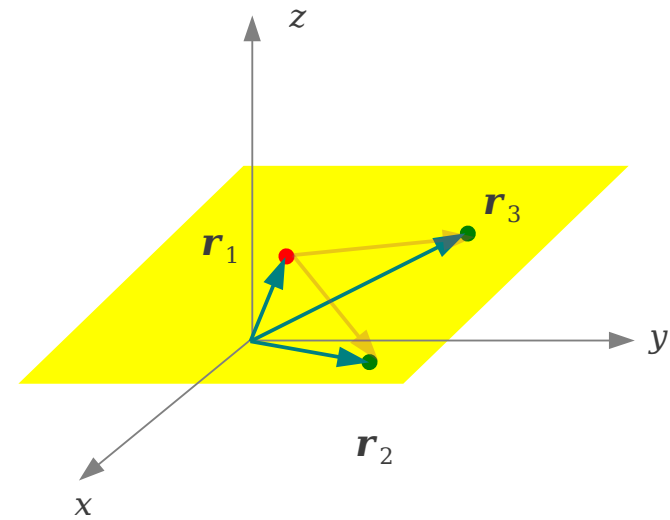
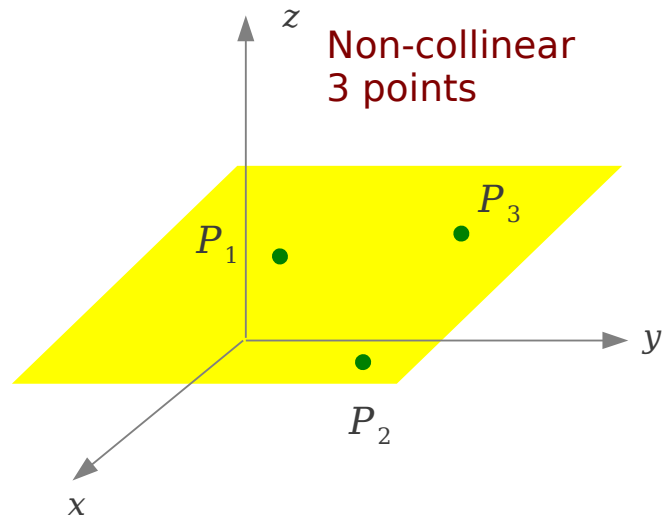
Graph of a plane



Line intersection of two planes

Point of intersection of a line and plane

# Normal Vector & 3 Points



# Vector Triple Product

$$\mathbf{a} \times (\mathbf{b} \times \mathbf{c})$$

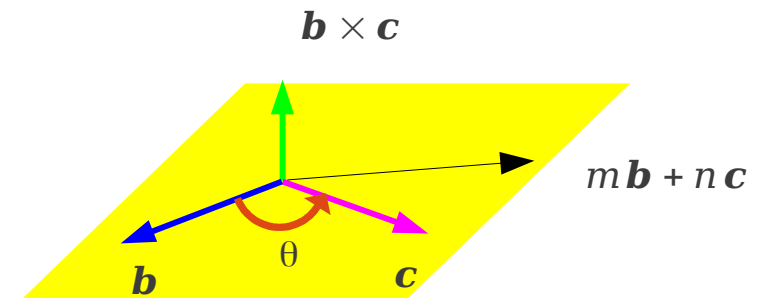
⇒ Perpendicular to  $\mathbf{b} \times \mathbf{c}$

⇒ Any vector perpendicular to  $\mathbf{b} \times \mathbf{c}$   
lies in the plane perpendicular to  $\mathbf{b} \times \mathbf{c}$

⇒ lies in the plane of  $\mathbf{b}$  and  $\mathbf{c}$

Perpendicular to the plane of

$$\mathbf{a} \times (\mathbf{b} \times \mathbf{c}) \Rightarrow m\mathbf{b} + n\mathbf{c}$$
$$(\mathbf{a} \cdot \mathbf{c})\mathbf{b} - (\mathbf{a} \cdot \mathbf{b})\mathbf{c}$$



# Scalar Triple Product

$$\mathbf{a} \cdot (\mathbf{b} \times \mathbf{c})$$

$$\mathbf{a} = a_1\mathbf{i} + a_2\mathbf{j} + a_3\mathbf{k}$$

$$\mathbf{b} = b_1\mathbf{i} + b_2\mathbf{j} + b_3\mathbf{k}$$

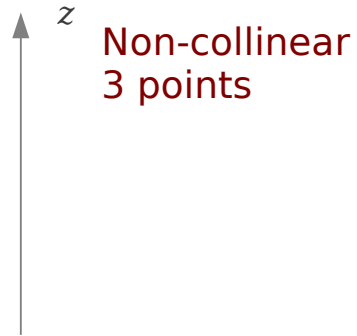
$$\mathbf{c} = c_1\mathbf{i} + c_2\mathbf{j} + c_3\mathbf{k}$$

$$\mathbf{b} \times \mathbf{c} = \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ b_1 & b_2 & b_3 \\ c_1 & c_2 & c_3 \end{vmatrix} = \mathbf{i} \begin{vmatrix} b_2 & b_3 \\ c_2 & c_3 \end{vmatrix} - \mathbf{j} \begin{vmatrix} b_1 & b_3 \\ c_1 & c_3 \end{vmatrix} + \mathbf{k} \begin{vmatrix} b_1 & b_2 \\ c_1 & c_2 \end{vmatrix}$$

$$\begin{aligned} \mathbf{a} \cdot (\mathbf{b} \times \mathbf{c}) &= (a_1\mathbf{i} + a_2\mathbf{j} + a_3\mathbf{k}) \cdot \left( \mathbf{i} \begin{vmatrix} b_2 & b_3 \\ c_2 & c_3 \end{vmatrix} - \mathbf{j} \begin{vmatrix} b_1 & b_3 \\ c_1 & c_3 \end{vmatrix} + \mathbf{k} \begin{vmatrix} b_1 & b_2 \\ c_1 & c_2 \end{vmatrix} \right) \\ &= \left( a_1 \begin{vmatrix} b_2 & b_3 \\ c_2 & c_3 \end{vmatrix} - a_2 \begin{vmatrix} b_1 & b_3 \\ c_1 & c_3 \end{vmatrix} + a_3 \begin{vmatrix} b_1 & b_2 \\ c_1 & c_2 \end{vmatrix} \right) = \begin{vmatrix} a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \\ c_1 & c_2 & c_3 \end{vmatrix} \end{aligned}$$



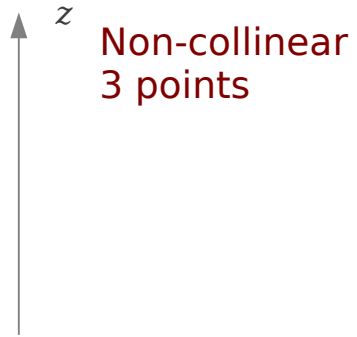
# Normal Vector & 3 Points



$$\mathbf{a} \times \mathbf{b} = \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \end{vmatrix} = \mathbf{i} \begin{vmatrix} a_2 & a_3 \\ b_2 & b_3 \end{vmatrix} - \mathbf{j} \begin{vmatrix} a_1 & a_3 \\ b_1 & b_3 \end{vmatrix} + \mathbf{k} \begin{vmatrix} a_1 & a_2 \\ b_1 & b_2 \end{vmatrix}$$

# Normal Vector & 3 Points

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## References

- [1] <http://en.wikipedia.org/>
- [2] <http://planetmath.org/>
- [3] M.L. Boas, “Mathematical Methods in the Physical Sciences”
- [4] D.G. Zill, “Advanced Engineering Mathematics”