

# MA2104 Assignment 1

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28th January 2018

## Problem 1

Vector parallel to  $L_1, \overrightarrow{AB} = \langle 1, 0, -1 \rangle$ , vector parallel to  $L_2, \overrightarrow{CD} = \langle -2, 5, -1 \rangle$ .

$$L_1 : \langle 1, 1, 1 \rangle + s \langle 1, 0, -1 \rangle,$$

$$L_2 : \langle 3, 0, -1 \rangle + t \langle -2, 5, -1 \rangle.$$

Find a vector orthogonal to both  $\overrightarrow{AB}$  and  $\overrightarrow{CD}$ ,

$$\mathbf{n} := \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ 1 & 0 & -1 \\ -2 & 5 & -1 \end{vmatrix} = \langle 5, 3, 5 \rangle.$$

The shortest distance is the absolute value of scalar projection of  $\overrightarrow{AC} = \langle 2, -1, -2 \rangle$  on  $\mathbf{n}$ .

$$\begin{aligned} \left| \text{comp}_{\mathbf{n}} \overrightarrow{AC} \right| &= \left| \frac{\overrightarrow{AC} \cdot \mathbf{n}}{\|\mathbf{n}\|} \right| \\ &= \left| \frac{-3}{\sqrt{59}} \right| = \frac{3}{\sqrt{59}}. \end{aligned}$$

□

## Problem 2

A vector orthogonal to both  $\mathbf{j} - \mathbf{k}$  and  $\mathbf{i} + \mathbf{j}$  will be their cross product,

$$\mathbf{n} := \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ 0 & 1 & -1 \\ 1 & 1 & 0 \end{vmatrix} = \langle 1, -1, -1 \rangle.$$

Two unit vectors orthogonal to  $\mathbf{j} - \mathbf{k}$  and  $\mathbf{i} + \mathbf{j}$  are

$$\begin{aligned} \frac{\mathbf{n}}{\|\mathbf{n}\|} &= \frac{1}{\sqrt{3}} \langle 1, -1, -1 \rangle \\ &= \left\langle \frac{1}{\sqrt{3}}, -\frac{1}{\sqrt{3}}, -\frac{1}{\sqrt{3}} \right\rangle, \text{ and} \\ -\frac{\mathbf{n}}{\|\mathbf{n}\|} &= \left\langle -\frac{1}{\sqrt{3}}, \frac{1}{\sqrt{3}}, \frac{1}{\sqrt{3}} \right\rangle. \end{aligned}$$

□

**Problem 3**

$\overrightarrow{PQ} = \langle 2, 3, 1 \rangle$ ,  $\overrightarrow{PS} = \langle 4, 2, 5 \rangle$ ,  $\overrightarrow{QR} = \langle 4, 2, 5 \rangle$ ,  $\overrightarrow{SR} = \langle 2, 3, 1 \rangle$ . Parallelogram is spanned by vectors  $\overrightarrow{PQ}$  and  $\overrightarrow{PS}$ .

$$\begin{aligned} \text{area} &= \left\| \overrightarrow{PQ} \times \overrightarrow{PS} \right\| = \left\| \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ 2 & 3 & 1 \\ 4 & 2 & 5 \end{vmatrix} \right\| \\ &= \left\| \langle 13, -6, -8 \rangle \right\| = \sqrt{269}. \end{aligned} \quad \square$$

**Problem 4**

$\overrightarrow{PQ} = \langle 1, 2, 1 \rangle$ ,  $\overrightarrow{PR} = \langle 5, 0, -2 \rangle$ , a vector normal to the plane will be their cross product.

$$\begin{aligned} \mathbf{n} &:= \overrightarrow{PQ} \times \overrightarrow{PR} = \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ 1 & 2 & 1 \\ 5 & 0 & -2 \end{vmatrix} \\ &= \langle -4, 7, -10 \rangle \end{aligned}$$

Define point  $S$  as  $\overrightarrow{OS} := \overrightarrow{OP} + \overrightarrow{PQ} + \overrightarrow{PR}$ . Area of triangle  $PQR$  is half the area of parallelogram  $PQRS$ , which can be computed as  $\|\mathbf{n}\|$ . Therefore

$$\begin{aligned} \text{area of } PQR &= \frac{1}{2} \|\mathbf{n}\| \\ &= \frac{\sqrt{165}}{2} \end{aligned} \quad \square$$

**Problem 5**

$$\begin{aligned} \text{signed volume} &= \mathbf{a} \cdot (\mathbf{b} \times \mathbf{c}) \\ &= \begin{vmatrix} 1 & 1 & -1 \\ 1 & -1 & 1 \\ -1 & 1 & 1 \end{vmatrix} \\ &= -1 - 1 - 1 + 1 - 1 - 1 \\ &= -4 \end{aligned}$$

Therefore volume of parallelepiped is 4. □

### Problem 6

To show  $\mathbf{v} := (\mathbf{a} \times \mathbf{b}) + (\mathbf{b} \times \mathbf{c}) + (\mathbf{c} \times \mathbf{a})$  is perpendicular to the plane containing  $P, Q, R$ , it suffices to show that the vector is orthogonal to both  $\overrightarrow{PQ}$  and  $\overrightarrow{PR}$ .

$\overrightarrow{PQ} = \mathbf{b} - \mathbf{a}$ . To check for orthogonality, compute  $\mathbf{v} \cdot \overrightarrow{PQ}$  as follows,

$$\begin{aligned}
 & ((\mathbf{a} \times \mathbf{b}) + (\mathbf{b} \times \mathbf{c}) + (\mathbf{c} \times \mathbf{a})) \cdot (\mathbf{b} - \mathbf{a}) \\
 &= (\mathbf{a} \times \mathbf{b}) \cdot (\mathbf{b} - \mathbf{a}) + (\mathbf{b} \times \mathbf{c}) \cdot (\mathbf{b} - \mathbf{a}) + (\mathbf{c} \times \mathbf{a}) \cdot (\mathbf{b} - \mathbf{a}) \\
 &= \underbrace{(\mathbf{a} \times \mathbf{b}) \cdot \mathbf{b}}_0 - \underbrace{(\mathbf{a} \times \mathbf{b}) \cdot \mathbf{a}}_0 + \underbrace{(\mathbf{b} \times \mathbf{c}) \cdot \mathbf{b}}_0 - (\mathbf{b} \times \mathbf{c}) \cdot \mathbf{a} + (\mathbf{c} \times \mathbf{a}) \cdot \mathbf{b} - \underbrace{(\mathbf{c} \times \mathbf{a}) \cdot \mathbf{a}}_0 \\
 &= -(\mathbf{b} \times \mathbf{c}) \cdot \mathbf{a} + (\mathbf{c} \times \mathbf{a}) \cdot \mathbf{b} \quad \text{(matrix with duplicate rows has det 0)} \\
 &= (\mathbf{c} \times \mathbf{b}) \cdot \mathbf{a} + (\mathbf{c} \times \mathbf{a}) \cdot \mathbf{b} \quad \text{(by anticommutativity of } \times \text{)}
 \end{aligned}$$

By computing  $\mathbf{a} \cdot (\mathbf{c} \times \mathbf{b})$  and  $\mathbf{b} \cdot (\mathbf{c} \times \mathbf{a})$ , it is clear that by swapping the 1st row with the 3rd row of the determinant in  $\mathbf{a} \cdot (\mathbf{c} \times \mathbf{b})$ ,  $\mathbf{b} \cdot (\mathbf{c} \times \mathbf{a})$  is obtained. Thus by property of determinant,  $\mathbf{a} \cdot (\mathbf{c} \times \mathbf{b}) = -\mathbf{b} \cdot (\mathbf{c} \times \mathbf{a})$  and we have  $\mathbf{v} \cdot \overrightarrow{PQ} = 0$ , so  $\mathbf{v} \perp \overrightarrow{PQ}$ .

Similarly, we can compute  $\mathbf{v} \cdot \overrightarrow{PR}$ , where  $\overrightarrow{PR} = (\mathbf{c} - \mathbf{a})$ ,

$$\begin{aligned}
 & ((\mathbf{a} \times \mathbf{b}) + (\mathbf{b} \times \mathbf{c}) + (\mathbf{c} \times \mathbf{a})) \cdot (\mathbf{c} - \mathbf{a}) \\
 &= (\mathbf{a} \times \mathbf{b}) \cdot (\mathbf{c} - \mathbf{a}) + (\mathbf{b} \times \mathbf{c}) \cdot (\mathbf{c} - \mathbf{a}) + (\mathbf{c} \times \mathbf{a}) \cdot (\mathbf{c} - \mathbf{a}) \\
 &= (\mathbf{a} \times \mathbf{b}) \cdot \mathbf{c} - \underbrace{(\mathbf{a} \times \mathbf{b}) \cdot \mathbf{a}}_0 + \underbrace{(\mathbf{b} \times \mathbf{c}) \cdot \mathbf{c}}_0 - (\mathbf{b} \times \mathbf{c}) \cdot \mathbf{a} + \underbrace{(\mathbf{c} \times \mathbf{a}) \cdot \mathbf{c}}_0 - \underbrace{(\mathbf{c} \times \mathbf{a}) \cdot \mathbf{a}}_0 \\
 &= (\mathbf{a} \times \mathbf{b}) \cdot \mathbf{c} - (\mathbf{b} \times \mathbf{c}) \cdot \mathbf{a} \\
 &= (\mathbf{a} \times \mathbf{b}) \cdot \mathbf{c} + (\mathbf{c} \times \mathbf{b}) \cdot \mathbf{a}
 \end{aligned}$$

By a similar computation, we can determine that  $(\mathbf{a} \times \mathbf{b}) \cdot \mathbf{c} = -(\mathbf{c} \times \mathbf{b}) \cdot \mathbf{a}$ , implying  $\mathbf{v} \cdot \overrightarrow{PR} = 0$ , so we have  $\mathbf{v} \perp \overrightarrow{PR}$ . This completes the proof.  $\square$

### Problem 7

Compute signed volume of parallelepiped spanned by  $\mathbf{a}, \mathbf{b}$  and  $\mathbf{c}$ .

$$\begin{aligned}
 \text{signed volume} &= \begin{vmatrix} 2 & 4 & -8 \\ 3 & -1 & 3 \\ -5 & 11 & -25 \end{vmatrix} \\
 &= 50 - 60 - 264 + 40 - 66 + 300 \\
 &= 0
 \end{aligned}$$

This implies that the parallelepiped spanned by  $\mathbf{a}, \mathbf{b}$  and  $\mathbf{c}$  is in fact a plane, meaning that the vectors are coplanar.  $\square$