

# CS 447/547: Computer Graphics

## Homework 1 Solutions

This homework must be done individually. Submission date is October 05, 2016, in class.

**Total points: 21**

**Question 1:** Vectors are very important to computer graphics and they are used to represent both locations in space (points) and directions. Assume you have three points in 2D space, represented by  $\mathbf{a} = [a_x, a_y]$ ,  $\mathbf{b} = [b_x, b_y]$ , and  $\mathbf{c} = [c_x, c_y]$ .

- a. How do you find the direction vector  $\mathbf{v}$  that points *from*  $\mathbf{a}$  *toward*  $\mathbf{b}$ ? (1 point)

$$\mathbf{v} = \mathbf{b} - \mathbf{a} \text{ or } \mathbf{v} = [b_x - a_x, b_y - a_y]$$

- b. How is the length,  $\|\mathbf{v}\|$ , of  $\mathbf{v}$  computed? (1 point)

$$\|\mathbf{v}\| = \sqrt{v_x^2 + v_y^2} \text{ or } \|\mathbf{v}\| = \sqrt{(b_x - a_x)^2 + (b_y - a_y)^2}$$

- c. A *unit vector*,  $\hat{\mathbf{v}}$ , in the direction  $\mathbf{v}$  is a vector in the same direction as  $\mathbf{v}$  but with length 1. How do you compute  $\hat{\mathbf{v}}$ ? Computing  $\hat{\mathbf{v}}$  is also referred to as *normalizing*  $\mathbf{v}$ . (1 point)

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

**Question 2:** Consider two vectors in 3D,  $\mathbf{a}$  and  $\mathbf{b}$ .

- a. How is the dot product  $\mathbf{a} \cdot \mathbf{b}$  computed? (1 point)

$$\mathbf{a} \cdot \mathbf{b} = a_x b_x + a_y b_y + a_z b_z$$

- b. What is the relationship between  $\mathbf{a} \cdot \mathbf{b}$  and the angle between  $\mathbf{a}$  and  $\mathbf{b}$ ? (1 point)

$$\mathbf{a} \cdot \mathbf{b} = \|\mathbf{a}\| \|\mathbf{b}\| \cos \theta, \text{ where } \theta \text{ is the angle between } \mathbf{a} \text{ and } \mathbf{b}.$$

- c. How is the cross product vector  $\mathbf{c} = \mathbf{a} \times \mathbf{b}$  computed? (1 point)

$$\mathbf{c} = \mathbf{a} \times \mathbf{b} = [a_y b_z - a_z b_y, a_z b_x - a_x b_z, a_x b_y - a_y b_x]$$

- d. What is the geometric relationship between  $\mathbf{a}$ ,  $\mathbf{b}$  and  $\mathbf{c}$ ? (1 point)

$\mathbf{c}$  is a vector perpendicular to both  $\mathbf{a}$  and  $\mathbf{b}$ .

- e. What is the geometric relationship between  $\mathbf{a} \times \mathbf{b}$  and  $\mathbf{b} \times \mathbf{a}$ ? (1 point)

They are the vectors pointing in opposite directions with the same length. Put another way,  $\mathbf{a} \times \mathbf{b} = -(\mathbf{b} \times \mathbf{a})$ .

- f. What is the relationship between  $\mathbf{a} \times \mathbf{b}$  and the angle between  $\mathbf{a}$  and  $\mathbf{b}$ ? (1 point)

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

**Question 3:** What is the solution to the following quadratic equation? (2 points)

$$x^2 + 3x + 2 = 0$$

There are two solutions: -1 and -2.

**Question 4:** What is the distance from a 2D point  $\mathbf{p} = [p_x, p_y]$  to a line  $ax + by + c = 0$ ? (3 points)

$$d = \frac{|ap_x + bp_y + c|}{\sqrt{a^2 + b^2}}$$

**Question 5:** This question concerns the definition of a 3D parametric line.

- a. What is the minimum number of points needed to define a unique line in 3D that passes through all the points? What other conditions must the points satisfy for the line to be unique? (2 points)

We need at least two points to define a unique line in 3D. These two points should not be identical.

- b. Given more than the minimum number of points, is it in general possible to find one line that passes through all of them? (1 point)

No.

- c. A 3D parametric line is usually defined as  $\mathbf{p} = \mathbf{o} + t\mathbf{d}$ . Label your points  $\mathbf{p}_1$ ,  $\mathbf{p}_2$ , etc. Find two vectors  $\mathbf{o}$  and  $\mathbf{d}$  in terms of the points. (2 points)

There is no unique solution to this question. One solution is as follows:

$$\mathbf{o} = \mathbf{p}_1 \text{ and } \mathbf{d} = \mathbf{p}_2 - \mathbf{p}_1$$

**Question 6:** What is the result of the following matrix multiplication of a vector? (2 points)

$$\begin{bmatrix} 1 & 2 & 5 \\ 4 & 1 & 12 \\ 3 & 1 & 15 \end{bmatrix} \begin{bmatrix} 2 \\ 1 \\ 3 \end{bmatrix}$$

$$\begin{bmatrix} 1 & 2 & 5 \\ 4 & 1 & 12 \\ 3 & 1 & 15 \end{bmatrix} \begin{bmatrix} 2 \\ 1 \\ 3 \end{bmatrix} = \begin{bmatrix} 19 \\ 45 \\ 52 \end{bmatrix}$$