

## PROBLEM SET 0

16822 GEOMETRY-BASED METHODS IN VISION (FALL 2023)

<https://piazza.com/cmu/fall2023/16822>

OUT: Aug. 31, 2023

DUE: Sep. 07, 2023 11:59 PM

Instructor: Shubham Tulsiani

TAs: Ben Eisner, Nupur Kumari

### START HERE: Instructions

- **Collaboration policy:** All are encouraged to work together BUT you must do your own work (code and write up). If you work with someone, please include their name in your write up and cite any code that has been discussed. If we find highly identical write-ups or code without proper accreditation of collaborators, we will take action according to university policies, i.e. you will likely fail the course. See the [Academic Integrity Section](#) detailed in the initial lecture for more information.
- **Submitting your work:**
  - We will be using Gradescope (<https://gradescope.com/>) to submit the Problem Sets. Please use the provided template. Submissions can be written in LaTeX. Regrade requests can be made, however this gives the TA the opportunity to regrade your entire paper, meaning if additional mistakes are found then points will be deducted. Each derivation/proof should be completed on a separate page. For short answer questions you **should** include your work in your solution.
- **Materials:** The data that you will need in order to complete this assignment is posted along with the writeup and template on Piazza.

For multiple choice or select all that apply questions, replace `\choice` with `\CorrectChoice` to obtain a shaded box/circle, and don't change anything else.

For questions where you must fill in a blank, please make sure your final answer is fully included in the given space. You may cross out answers or parts of answers, but the final answer must still be within the given space. We accept either LaTeX pdfs or scanned documents as long as the location of each question is annotated properly.

## 1 Vector Spaces [16pts]

1. [4 pts] Which of the following subsets of  $\mathbb{R}^3$  are vector spaces? **Select all that are true:**

- ☐ The plane formed by the vector  $(v_1, v_2, v_3)$  such that  $v_1 = v_2$
- ☐ The plane formed by the vector  $(v_1, v_2, v_3)$  such that  $v_1 = 1$
- ☐ The plane formed by the vector  $(v_1, v_2, v_3)$  such that  $v_1 v_2 v_3 = 0$
- ☐ All linear combinations of  $\mathbf{v} = (1, 4, 0)$  and  $\mathbf{w} = (2, 2, 2)$

2. [4 pts] For the following questions, consider a matrix  $\mathbf{A} \in \mathbb{R}^{m \times n}$  and a vector  $\mathbf{b} \in \mathbb{R}^n$ . Answer True or false (with a counterexample if false): **Select all that are true:**

- ☐ The vectors  $\mathbf{b}$  that are not in the column space  $\mathbf{C}(\mathbf{A})$  form a subspace.
- ☐ If  $\mathbf{C}(\mathbf{A})$  contains only zero vectors, then  $\mathbf{A}$  is the zero matrix.
- ☐ The column space of the matrix  $2\mathbf{A}$  equals the column space of  $\mathbf{A}$
- ☐ The column space of the matrix  $\mathbf{A} - \mathbf{I}$  equals the column space of  $\mathbf{A}$

3. [4 pts] Create a  $3 \times 4$  matrix whose solution to  $\mathbf{A}\mathbf{x} = \mathbf{0}$  is the  $\mathbf{s}_1 = \begin{bmatrix} -3 \\ 1 \\ 0 \\ 0 \end{bmatrix}$  and  $\mathbf{s}_2 = \begin{bmatrix} -2 \\ 0 \\ -6 \\ 0 \end{bmatrix}$

4. [4 pts] If a  $3 \times 4$  matrix has rank 3, what are its column space and left nullspace?

## 2 Eigenvalues, Eigenvector, Singular Value Decomposition [32 pts]

1. [4 pts] Deduce the Eigenvalue and Eigenvectors of  $\mathbf{A}$ :

$$\begin{bmatrix} 1 & 2 \\ 2 & 4 \end{bmatrix}$$

2. [4 pts] For

$$\mathbf{A} = \begin{bmatrix} 2 & -1 \\ -1 & 2 \end{bmatrix}$$

Find the Eigenvalues and Eigenvectors of  $\mathbf{A}$ ,  $\mathbf{A}^2$  and  $\mathbf{A}^{-1}$  and  $\mathbf{A} + 4\mathbf{I}$

3. [4 pts]  $\mathbf{A} \in \mathbb{R}^{m \times n}$  is positive definite if for any **non-zero** vector  $\mathbf{x} \in \mathbb{R}^n$  we have  $\mathbf{x}^\top \mathbf{A} \mathbf{x} > 0$ :

$$\mathbf{x}^\top \mathbf{A} \mathbf{x} = \begin{bmatrix} x & y \end{bmatrix} \begin{bmatrix} a & b \\ b & c \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}$$

Test matrices  $\mathbf{C}$  and  $\mathbf{D}$  for positive definiteness

$$\mathbf{C} = \begin{bmatrix} 2 & -1 & 0 \\ -1 & 2 & -1 \\ 0 & -1 & 2 \end{bmatrix}; \mathbf{D} = \begin{bmatrix} 2 & -1 & b \\ -1 & 2 & -1 \\ b & -1 & 2 \end{bmatrix}$$

4. [6 pts] Estimate the singular values  $\sigma_1$  and  $\sigma_2$  of the matrix  $\mathbf{A}$

$$\mathbf{A} = \begin{bmatrix} 1 & 0 \\ C & 1 \end{bmatrix}$$

5. [6 pts] Find the pseudoinverse of  $\mathbf{A} \in \mathbb{R}^{m \times n}$

$$\mathbf{A} = \begin{bmatrix} 2 & 2 \\ 1 & 1 \end{bmatrix}$$

6. [8 pts] Suppose the following information is known about matrix  $\mathbf{A}$ :

$$\mathbf{A} \begin{bmatrix} 1 \\ 2 \\ 1 \end{bmatrix} = 6 \begin{bmatrix} 1 \\ 2 \\ 1 \end{bmatrix}, \quad \mathbf{A} \begin{bmatrix} 1 \\ -1 \\ 1 \end{bmatrix} = 3 \begin{bmatrix} 1 \\ -1 \\ 1 \end{bmatrix}, \quad \mathbf{A} \begin{bmatrix} 2 \\ -1 \\ 0 \end{bmatrix} = 3 \begin{bmatrix} 1 \\ -1 \\ 1 \end{bmatrix}$$

I [4 pts] Find the eigenvalues of  $\mathbf{A}$

II [4 pts] In each of the following subquestions, please justify with a reason (based on the theory of eigenvalues and eigenvectors).

- (a) Is  $\mathbf{A}$  a diagonalizable matrix?  
(b) Is  $\mathbf{A}$  an invertible matrix?

**Attendance Question:** Among Lectures 1-4, how many did you attend in person?

**Collaboration Questions** Please answer the following:

1. Did you receive any help whatsoever from anyone in solving this assignment?

☐ Yes

☐ No

- If you answered 'Yes', give full details:
- (e.g. "Jane Doe explained to me what is asked in Question 3.4")

2. Did you give any help whatsoever to anyone in solving this assignment?

☐ Yes

☐ No

- If you answered 'Yes', give full details:
- (e.g. "I pointed Joe Smith to section 2.3 since he didn't know how to proceed with Question 2")

3. Did you find or come across code that implements any part of this assignment ?

☐ Yes

☐ No

- If you answered 'Yes', give full details: No
- (book & page, URL & location within the page, etc.).

A large, empty rectangular box with a thin black border, intended for the student to provide their answer to the problem.