

MIDTERM EXAM 3

DATE : Nov. 8 (WED)

TIME : 6:30 PM - 7:45 PM

PLACE : SECTION A - BOGGS B5
(8:25)

SECTION E - HOWEY-PHYSICS
(11:00) L3

COVERAGE : UP TO 6.6.

REVIEW : Nov 8 in CLASS

(SAMPLE EXAMS : S22, F22,
 ↑ S23)
 MASTER WEBPAGE .

Math 1554 Linear Algebra Spring 2023

Midterm 3

PLEASE PRINT YOUR NAME CLEARLY IN ALL CAPITAL LETTERS

Name: _____ GTID Number: _____

Student GT Email Address: _____@gatech.edu

Section Number (e.g. A3, G2, etc.) _____ TA Name _____

Circle your instructor:

Prof Kim Prof Barone Prof Schroeder Prof Kumar

Student Instructions

- **Show your work** and justify your answers for all questions unless stated otherwise.
- **Organize your work** in a reasonably neat and coherent way.
- **Simplify your answers** unless explicitly stated otherwise.
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- Leave a 1 inch border around the edges of exams.
- The last page is for scratch work. Please use it if you need extra space.
- This exam has 8 pages of questions.

Midterm 3. Your initials: _____

You do not need to justify your reasoning for questions on this page.

1. (a) (6 points) Suppose A is a real $m \times n$ matrix and $\vec{b} \in \mathbb{R}^m$ unless otherwise stated. Select **true** if the statement is true for all choices of A and \vec{b} . Otherwise, select **false**.

true false

- If the projection of vector \vec{y} onto subspace W is equal to the zero vector, then $\vec{y} \in W^\perp$.
- If A and B are $n \times n$ orthogonal matrices, then AB is also $n \times n$ and orthogonal.
- If $\{\vec{u}, \vec{v}\}$ is an orthonormal set in \mathbb{R}^n , then $\|\vec{u} + \vec{v}\| = \sqrt{2}$.
- If A is row equivalent to a diagonalizable matrix B , then A is diagonalizable.
- For any rectangular $m \times n$ matrix A , $(\text{Row}A)^\perp = (\text{Row}A^T A)^\perp$.
- If A has the QR factorization $A = QR$, then $\text{Col}A = \text{Col}Q$.
-

- (b) (2 points) Indicate whether the following situations are possible or impossible.

possible impossible

- A 2×2 real matrix A with eigenvalues $1 + i$ and $-1 - i$.
- A diagonalizable matrix A that is similar to $\begin{pmatrix} 1 & 2 \\ 0 & 1 \end{pmatrix}$.

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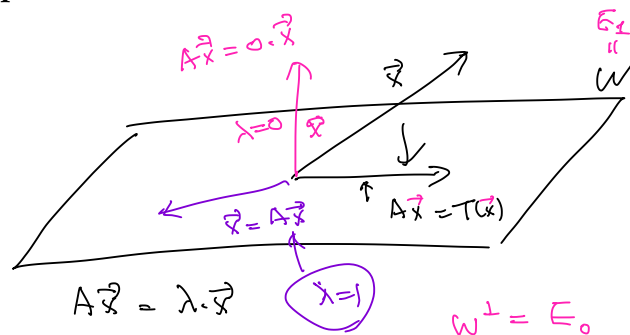
(c) (2 points) $\{\vec{v}_1, \vec{v}_2, \vec{v}_3\}$ is an orthonormal basis for subspace V . Fill in circles next to orthogonal bases for V ; leave the other circles empty.

- $\{\vec{v}_1, \vec{v}_2\}$
- $\{\vec{v}_3, 4\vec{v}_1, 3\vec{v}_2\}$
- $\{\vec{v}_1 + \vec{v}_2, \vec{v}_1 - \vec{v}_2, \vec{v}_3\}$
- $\{\vec{v}_1, \vec{v}_1 + \vec{v}_2, \vec{v}_1 + \vec{v}_2 + \vec{v}_3\}$

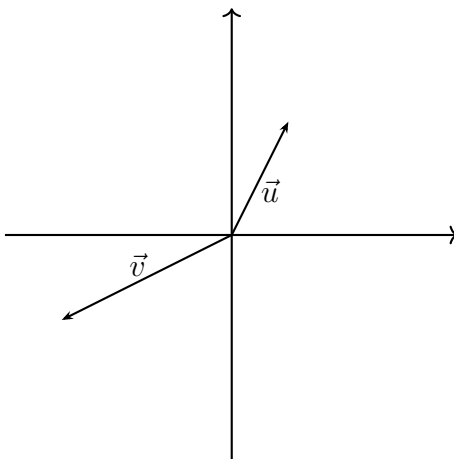
0 : eigenvalue $\Rightarrow \det(A - 0 \cdot I) = 0$

(d) (2 points) Let W be a 4-dimensional subspace of \mathbb{R}^5 and let A be the standard matrix for the orthogonal projection onto W . The following situations are either possible or impossible. Fill in the circles next to the **possible** situations; leave the other circles empty.

- A is invertible. \times
- A has eigenvalue zero. \circ
- $\text{Nul}A = W$. \perp
- $A\vec{v} = \vec{v}$, for some vector $\vec{v} \in \mathbb{R}^5$. \forall



2. (1 point) In the graph below, sketch $\text{proj}_{\vec{u}}(\vec{v})$.



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3. (9 points) Fill in the blanks.

$$\dim(\text{Col}(A)) + \dim(\text{Col}(A)^\perp) = \dim(\mathbb{R}^{20})$$

(a) If A is 20×25 and $\dim(\text{Col}(A)^\perp) = 10$, the rank of A is .

(b) If A is an $n \times n$ orthogonal matrix, $A^T A$ is equal to .

(c) The distance between vector $\vec{u} = \begin{pmatrix} 2 \\ 3 \end{pmatrix}$ and subspace $W = \text{Span}(\vec{v})$, where $\vec{v} = \begin{pmatrix} 1 \\ 0 \end{pmatrix}$ is equal to .

(d) If u and v are orthogonal vectors in \mathbb{R}^n and the columns of $A \in \mathbb{R}^{n \times n}$ are orthonormal, then $(Au) \cdot (Av)$ is equal to (a number).

(e) If $\vec{b} = \begin{pmatrix} 3 \\ -1 \end{pmatrix}$, $\vec{u} = \begin{pmatrix} 1 \\ 1 \end{pmatrix}$, $W = \text{Span}(\vec{u})$, then $\text{proj}_W \vec{b}$ is the vector .

(f) If $\vec{v} = \begin{pmatrix} 1 \\ 2 \end{pmatrix}$, $W = \text{Span}(\vec{v})$, a basis for W^\perp is the vector .

(g) If A is 32×9 and $A\vec{x} = \vec{b}$ has a unique least squares solution \hat{x} for every \vec{b} in \mathbb{R}^{32} , then the number of pivot columns in A is .

(h) If A is 30×8 and $\dim(\text{Row}(A)^\perp) = 1$, then rank A is equal to .

(i) If $W = \text{Span} \left\{ \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix} \right\}$, then $\dim W^\perp =$.

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4. (4 points) If possible, give examples of the following. If it is not possible, write NP.

(a) A 4×5 non-zero matrix, A , in RREF, that satisfies $\dim(\underbrace{(\text{Row}(A))^\perp}_{\text{Null}(A)}) = 3$.

$$A = \begin{pmatrix} 1 & 0 & * & * & * \\ 0 & 1 & * & * & * \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

Null(A)

(b) A 2×3 matrix such that $\text{Col}(A)^\perp$ is spanned by $\begin{pmatrix} 2 \\ 1 \end{pmatrix}$.

Null(A^T)

$$A = \begin{pmatrix} 1 & 0 & 3 \\ -2 & 0 & -6 \end{pmatrix}$$

$$A^T \begin{bmatrix} 2 \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & -2 \\ 0 & 0 \\ 3 & -6 \end{bmatrix} \begin{bmatrix} 2 \\ 1 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$

(c) A non-zero vector, \vec{w} , whose projection onto the space spanned by $\vec{v} = \begin{pmatrix} 1 \\ 2 \\ 3 \end{pmatrix}$ is the zero vector.

$$\vec{w} = \begin{pmatrix} 2 \\ -1 \\ 0 \end{pmatrix} \begin{matrix} a \\ b \\ c \end{matrix}$$

$$\vec{v} \cdot \vec{w} = 0$$

$$a + 2b + 3c = 0$$

(d) A 3×2 matrix A that is in echelon form, has QR factorization $A = QR$, and $A = Q$.

$$A = \begin{pmatrix} & \\ & \\ & \end{pmatrix}$$

5. (2 points) W is the subspace spanned by $\vec{u} = \begin{pmatrix} 1 \\ 0 \\ -4 \end{pmatrix}$. Give a basis for W^\perp .



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6. (2 points) Given that \vec{u}_1 and \vec{u}_2 form an orthogonal set, compute the projection of \vec{y} onto $S = \text{Span}\{\vec{u}_1, \vec{u}_2\}$.

$$\vec{u}_1 = \begin{pmatrix} 3 \\ 4 \\ 0 \end{pmatrix}, \quad \vec{u}_2 = \begin{pmatrix} -4 \\ 3 \\ 0 \end{pmatrix}, \quad \vec{y} = \begin{pmatrix} 6 \\ 3 \\ -2 \end{pmatrix}$$

$\text{proj}_S(\vec{y}) =$

7. (3 points) If $A = \begin{pmatrix} 2 & -1 \\ 1 & 2 \end{pmatrix}$ has eigenvalues λ_1, λ_2 with corresponding eigenvectors v_1, v_2 , and $\lambda_1 = 2 + i$, find λ_2, v_1, v_2 .

$\lambda_2 =$

$\vec{v}_1 =$

$\vec{v}_2 =$

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8. (4 points) **Show all work for problems on this page.** If $A = QR = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 & 1 \\ -1 & 1 \end{pmatrix} \begin{pmatrix} 2 & 2 \\ 0 & 1 \end{pmatrix}$, determine the least-squares solution to $A\hat{x} = \begin{pmatrix} \sqrt{2} \\ 2\sqrt{2} \end{pmatrix}$. You do not need to determine A .

$$\hat{x} = \begin{array}{|c|} \hline \\ \hline \end{array}$$

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9. (5 points) **Show all work for problems on this page.** Four points in \mathbb{R}^3 with coordinates (x, y, z) are $(2, 0, 1)$, $(0, -2, 1)$, $(1, -1, 3)$, and $(1, 1, 3)$. Determine the coefficients c_1 and c_2 for the plane $z = c_1x + c_2y$ that best fits the points using the method of least-squares.

$$c_1 = \boxed{} \quad c_2 = \boxed{}$$

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10. (4 points) **Show all work for problems on this page.** Write \vec{y} as the sum of a vector \hat{y} in $\text{Span}\{\vec{u}\}$ and a vector \vec{z} orthogonal to \vec{u} .

$$\vec{y} = \begin{pmatrix} 5 \\ 2 \\ 4 \\ 1 \end{pmatrix},$$

$$\vec{u} = \begin{pmatrix} 1 \\ 1 \\ 1 \\ 1 \end{pmatrix}$$

$$\hat{y} = \boxed{\phantom{\begin{pmatrix} \\ \\ \\ \end{pmatrix}}}$$

$$\vec{z} = \boxed{\phantom{\begin{pmatrix} \\ \\ \\ \end{pmatrix}}}$$

11. (4 points) Find matrices P and D such that $A = PDP^{-1}$ where D is a diagonal matrix and P is an invertible matrix.

$$A = \begin{bmatrix} 1 & 0 \\ 1 & 2 \end{bmatrix}$$

$$P = \boxed{\phantom{\begin{bmatrix} & \\ & \end{bmatrix}}}$$

$$D = \boxed{\phantom{\begin{bmatrix} & \\ & \end{bmatrix}}}$$

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Section Number (e.g. A3, G2, etc.) _____ TA Name _____

Circle your instructor:

Prof Vilaca Da Rocha Prof Kafer Prof Barone Prof Wheeler
Prof Blumenthal Prof Sun Prof Shirani

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1. (a) (8 points) Suppose A is an $m \times n$ matrix and $\vec{b} \in \mathbb{R}^m$ unless otherwise stated. Select **true** if the statement is true for all choices of A and \vec{b} . Otherwise, select **false**.

true false

- | | | | |
|-----------------------|----------------------------------|--|-------------------------|
| <input type="radio"/> | <input type="radio"/> | A matrix $A \in \mathbb{R}^{n \times n}$ and its transpose A^T have the same eigenvectors. | |
| <input type="radio"/> | <input type="radio"/> | An invertible matrix A is diagonalizable if and only if its inverse A^{-1} is diagonalizable. | |
| <input type="radio"/> | <input type="radio"/> | If $\vec{u} \cdot \vec{v} = \vec{u} \cdot \vec{w}$, then \vec{u} is orthogonal to $(\vec{w} - \vec{v})$. | |
| <input type="radio"/> | <input type="radio"/> | If the vectors \vec{u} and \vec{v} are orthogonal then $\ \vec{u} + \vec{v}\ = \ \vec{u}\ + \ \vec{v}\ $. | |
| <input type="radio"/> | <input checked="" type="radio"/> | If $\vec{y} \in \mathbb{R}^n$ is a nonzero vector and W is a subspace of \mathbb{R}^n , then $\ \text{proj}_W(\vec{y})\ $ is the shortest distance between W and \vec{y} . | |
| <input type="radio"/> | <input type="radio"/> | If $\vec{y} \in \mathbb{R}^n$ is a nonzero vector and W is a subspace of \mathbb{R}^n , then $\vec{y} - \text{proj}_W(\vec{y})$ is in W^\perp . | $2 = \beta_0 + \beta_1$ |
| <input type="radio"/> | <input type="radio"/> | If W is a subspace of \mathbb{R}^n and $\vec{y} \in \mathbb{R}^n$ such that $\vec{y} \cdot \vec{w} = 0$ for some vector $\vec{w} \in W$, then $\vec{y} \in W^\perp$. | $3 = \beta_0 + \beta_1$ |
| <input type="radio"/> | <input type="radio"/> | The line of best fit $y = \beta_0 + \beta_1 x$ for the points $(1, 2)$, $(1, 3)$, and $(1, 4)$ is unique. | $4 = \beta_0 + \beta_1$ |

$$\Rightarrow \begin{bmatrix} 1 & 1 \\ 1 & 1 \\ 1 & 1 \end{bmatrix} \begin{bmatrix} \beta_0 \\ \beta_1 \end{bmatrix} = \begin{bmatrix} 2 \\ 3 \\ 4 \end{bmatrix}$$

- (b) (4 points) Indicate whether the following situations are possible or impossible.

possible impossible

- | | | |
|-----------------------|-----------------------|---|
| <input type="radio"/> | <input type="radio"/> | A 5×5 real matrix A such that A has no real eigenvalues. |
| <input type="radio"/> | <input type="radio"/> | An $m \times n$ matrix U where $U^T U = I_n$ and $n > m$. |
| <input type="radio"/> | <input type="radio"/> | A 2-dimensional subspace W of \mathbb{R}^3 and a vector $\vec{y} \in W$ such that $\ \vec{v}_1 - \vec{y}\ = \ \vec{v}_2 - \vec{y}\ $ where $\vec{v}_1, \vec{v}_2 \in W^\perp$ and $\vec{v}_1 \neq \vec{v}_2$. |
| <input type="radio"/> | <input type="radio"/> | A matrix $A \in \mathbb{R}^{3 \times 4}$ such that the linear system $A\vec{x} = \vec{b}$ has a unique least-squares solution. |

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(c) (2 points) An $m \times n$ matrix $A = [\vec{a}_1 \ \cdots \ \vec{a}_n]$ has non-zero orthogonal columns and $A^T A = 2I_n$. Which of the following statements is FALSE?

- $(A\vec{x}) \cdot (A\vec{y}) = \vec{x} \cdot \vec{y}$ for every \vec{x} and \vec{y} in \mathbb{R}^n .
- $n \leq m$.
- If we apply the Gram-Schmidt process to $\{\vec{a}_1, \dots, \vec{a}_n\}$ we obtain the same set $\{\vec{a}_1, \dots, \vec{a}_n\}$.
- If $A = QR$ is the QR factorization of A , then R is a diagonal matrix.

2. (3 points) Find a, b, c so that the set of vectors $\{\vec{u}_1, \vec{u}_2, \vec{u}_3\}$ is an orthogonal set.

$$\vec{u}_1 = \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix} \quad \vec{u}_2 = \begin{pmatrix} -2 \\ 0 \\ a \end{pmatrix} \quad \vec{u}_3 = \begin{pmatrix} -1 \\ b \\ c \end{pmatrix}$$

$a =$	<input type="text"/>
$b =$	<input type="text"/>
$c =$	<input type="text"/>

Midterm 3. Your initials: _____

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3. (8 points) Fill in the blanks.

(a) Suppose \vec{u} and \vec{v} are orthogonal vectors in \mathbb{R}^n and that \vec{v} is a unit vector.

If $(2\vec{u} + \vec{v}) \cdot (\vec{u} + 5\vec{v}) = 13$, determine the length of \vec{u} .

$$\|\vec{u}\| = \boxed{}$$

(b) The normal equations for the least-squares solution to $A\vec{x} = \vec{b}$ are given by:

(c) Compute the length (magnitude) of the vector \vec{y} .

$$\vec{y} = \begin{pmatrix} \frac{1}{\sqrt{3}} & -\frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{6}} \\ \frac{1}{\sqrt{3}} & 0 & \frac{2}{\sqrt{6}} \\ \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{6}} \end{pmatrix} \begin{pmatrix} 1 \\ 2 \\ 3 \end{pmatrix}$$

$$\|\vec{y}\| = \boxed{}$$

(d) Let $A = \begin{bmatrix} 2 & -2 \\ 2 & 2 \end{bmatrix}$. The vector $\vec{v} = \begin{pmatrix} -1 - i \\ -1 + i \end{pmatrix}$ is an eigenvector of A . Find the associated eigenvalue λ for the eigenvector \vec{v} of A .

$$\lambda = \boxed{}$$

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4. (4 points) Fill in the blanks.

- (a) Let $W = \text{span} \left\{ \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix} \right\}$ and let $\vec{y} = \begin{pmatrix} 4 \\ 5 \\ 6 \end{pmatrix}$. Calculate the projection of \vec{y} onto the subspace W , and find the distance from \vec{y} to W .

$\text{proj}_W(\vec{y}) =$

$\text{dist}(\vec{y}, W) =$

- (b) Let $W = \text{span} \left\{ \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix}, \begin{pmatrix} 1 \\ 1 \\ 0 \end{pmatrix} \right\}$, $L = \text{span} \left\{ \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix} \right\}$. Find **all** vectors $\vec{u} \in L$ such that the distance from \vec{u} to W is equal to 2.

$2 = |c|$

$W = \text{span} \left\{ \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix}, \begin{pmatrix} 1 \\ 1 \\ 0 \end{pmatrix} \right\}$
orthogonal basis $\{u_1, u_2\}$

$\vec{u} = c \cdot \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix} = c_1 u_1 + c_2 u_2$

$\frac{u \cdot u_1}{u_1 \cdot u_1} \quad \frac{u \cdot u_2}{u_2 \cdot u_2}$

$\begin{pmatrix} 2 \\ 2 \\ 2 \end{pmatrix} \quad \begin{pmatrix} -2 \\ -2 \\ -2 \end{pmatrix} \quad u_1 = \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix} \quad , \quad u_2 = \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix}$

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5. (6 points) **Show all work for problems on this page.**

One of the eigenvalues of the matrix A is $\lambda = 1$. Diagonalize the matrix.

$$A = \begin{pmatrix} 1 & 1 & 1 \\ -1 & -1 & -1 \\ 1 & 1 & 1 \end{pmatrix}$$

$P =$

$D =$

6. (3 points) Find a matrix $A \in \mathbb{R}^{2 \times 2}$ such that \vec{v}_1 is an eigenvector of A with eigenvalue $\lambda_1 = 4$, and \vec{v}_2 is an eigenvector of A with eigenvalue $\lambda_2 = -3$.

$$\vec{v}_1 = \begin{pmatrix} 3 \\ 2 \end{pmatrix}, \quad \vec{v}_2 = \begin{pmatrix} 1 \\ 1 \end{pmatrix}.$$

$A =$

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7. (4 points) **Show all work for problems on this page.**

Let $\mathcal{B} = \{\vec{x}_1, \vec{x}_2, \vec{x}_3\}$ be a basis for a subspace W of \mathbb{R}^4 , where

$$\vec{x}_1 = \begin{pmatrix} 1 \\ -1 \\ 1 \\ -1 \end{pmatrix}, \quad \vec{x}_2 = \begin{pmatrix} -2 \\ 1 \\ 1 \\ 2 \end{pmatrix}, \quad \vec{x}_3 = \begin{pmatrix} 0 \\ 2 \\ -1 \\ -1 \end{pmatrix}.$$

(a) Apply the Gram-Schmidt process to the set of vectors $\{\vec{x}_1, \vec{x}_2, \vec{x}_3\}$ to find an orthogonal basis $\mathcal{H} = \{\vec{v}_1, \vec{v}_2, \vec{v}_3\}$ for W . Clearly show all steps of the Gram-Schmidt process.

$\mathcal{H} =$

(b) In the space below, **check** that the vectors in the basis \mathcal{H} form an orthogonal set.

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8. (4 points) **Show all work for problems on this page.**

If A has the following QR factorization

$$A = \frac{1}{2} \begin{pmatrix} 1 & 1 \\ -1 & 1 \\ 1 & 1 \\ 1 & -1 \end{pmatrix} \begin{pmatrix} 7 & 2 \\ 0 & 3 \end{pmatrix}, \text{ and } \vec{b} = \begin{pmatrix} 2 \\ 3 \\ 1 \\ 0 \end{pmatrix},$$

compute the least-square solution to the equation $A\vec{x} = \vec{b}$.

$$\hat{x} = \boxed{\phantom{\begin{matrix} \\ \\ \\ \end{matrix}}}$$

9. (4 points) Compute the least squares line $y = c_1 + c_2x$ that best fits the data

$$\begin{array}{c|ccc} x & -1 & 0 & 1 \\ \hline y & 4 & 2 & 5 \end{array}$$

$$\boxed{\phantom{\begin{matrix} \\ \\ \\ \end{matrix}}}$$

Math 1554 Linear Algebra Spring 2022

Midterm 3

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Circle your instructor:

Prof Barone Prof Shirani Prof Simone Prof Timko

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1. (a) (8 points) Suppose A is an $m \times n$ matrix and $\vec{b} \in \mathbb{R}^m$ unless otherwise stated. Select **true** if the statement is true for all choices of A and \vec{b} . Otherwise, select **false**.

true false

-
- The matrix $\begin{bmatrix} 1 & 0 & 0 \\ 0 & 2 & 0 \\ 0 & 0 & 1 \end{bmatrix}$ is diagonalizable.
- If W is the subspace of \mathbb{R}^3 spanned by $\begin{pmatrix} 1 \\ 2 \\ -1 \end{pmatrix}$ and $\begin{pmatrix} 3 \\ 0 \\ 1 \end{pmatrix}$, then $\begin{pmatrix} -1 \\ 1 \\ 1 \end{pmatrix}$ is a vector in W^\perp .
- If U is a 3×2 matrix with orthonormal columns, then for every $\vec{y} \in \text{Col}(U)$ we have $\vec{y} = UU^T\vec{y}$.
- If the matrix A has orthogonal columns, then $A^T A$ is a diagonal matrix.
- Assume $n \neq m$. If $A = QR$ is the QR factorization of $A \in \mathbb{R}^{n \times m}$, then $Q \in \mathbb{R}^{n \times n}$ and $R \in \mathbb{R}^{n \times m}$.
- If $A = QR$ is a QR factorization of A , then $A^T A = R^T R$.
- If \hat{x} and \hat{y} are least-squares solutions of $A\vec{x} = \vec{b}$, then $\hat{x} - \hat{y} \in \text{Nul}(A)$.
- Suppose A is such that T_A is not one-to-one, and \vec{b} is not in the range of T . Then $A\vec{x} = \vec{b}$ has a unique least-squares solution.

- (b) (4 points) Indicate whether the following situations are possible or impossible.

possible impossible

-
- A is a 7×7 diagonalizable matrix with exactly three distinct eigenvalues whose geometric multiplicities are 1, 2, and 3, respectively.
- \vec{u} and \vec{v} are nonzero vectors such that $\|\vec{u} + \vec{v}\|^2 = \|\vec{u}\|^2 + \|\vec{v}\|^2$.
- The distance between a vector $\vec{b} \in \mathbb{R}^m$ and the column space of a matrix $A \in \mathbb{R}^{m \times n}$ is zero, and the linear system $A\vec{x} = \vec{b}$ is inconsistent.
- \mathcal{W} is a 2-dimensional subspace of \mathbb{R}^3 , and there exists a linearly independent set of vectors $\{\vec{x}, \vec{y}\}$ in \mathbb{R}^3 such that $\text{Proj}_{\mathcal{W}}\vec{x} = \text{Proj}_{\mathcal{W}}\vec{y}$.
-

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You do not need to justify your reasoning for questions on this page.

(c) (2 points) The standard matrix of a linear transformation $T : \mathbb{R}^3 \rightarrow \mathbb{R}^3$ has orthonormal columns. Which one of the following statements is **false**?

Choose only one.

- $\|T(\vec{x})\| = \|\vec{x}\|$ for all \vec{x} in \mathbb{R}^3 .
- If two non-zero vectors \vec{x} and \vec{y} in \mathbb{R}^3 are scalar multiples of each other, then $\|T(\vec{x} + \vec{y})\|^2 = \|T(\vec{x})\|^2 + \|T(\vec{y})\|^2$.
- If \mathcal{P} is a parallelepiped in \mathbb{R}^3 , then the volume of $T(\mathcal{P})$ is equal to the volume of \mathcal{P} .
- T is one-to-one.

2. (2 points) Suppose that, in the QR factorization of A , we have Q as given below. Find R .

$$A = \begin{bmatrix} 1 & 1 \\ 1 & 1 \\ 1 & -1 \\ 1 & 1 \end{bmatrix} \quad Q = \frac{1}{2} \begin{bmatrix} 1 & 1/\sqrt{3} \\ 1 & 1/\sqrt{3} \\ 1 & -\sqrt{3} \\ 1 & 1/\sqrt{3} \end{bmatrix}$$

Note: Please fill in the blanks and do not place values in front of the matrix for this problem.

$$R = \begin{bmatrix} \underline{\hspace{1cm}} & \underline{\hspace{1cm}} \\ \underline{\hspace{1cm}} & \underline{\hspace{1cm}} \end{bmatrix}$$

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You do not need to justify your reasoning for questions on this page.

3. (2 points) Using **only** 0's and 1's in your answer, give an example of a 2×2 matrix that is invertible but not diagonalizable.

$$\left(\begin{array}{cc} & \\ & \end{array} \right)$$

4. (6 points) Fill in the blanks.

- (a) Let $\vec{u}, \vec{v} \in \mathbb{R}^n$ be orthogonal vectors each with length 2. Determine the length of the vector $2\vec{u} + \vec{v}$.
- (b) Suppose A is a 7×5 matrix such that $\dim(\text{Row } A)^\perp = 4$. Determine the dimension of the column space of A .
- (c) Suppose $\mathcal{B} = \{\vec{v}_1, \vec{v}_2\}$ is an orthogonal basis for a subspace \mathcal{W} of \mathbb{R}^n , and \vec{x} belongs to the subspace \mathcal{W} . Suppose also that

$$\vec{v}_1 \cdot \vec{v}_1 = 2, \vec{v}_2 \cdot \vec{v}_2 = 4, \vec{v}_1 \cdot \vec{x} = 6, \text{ and } \vec{v}_2 \cdot \vec{x} = -4.$$

Find $[\vec{x}]_{\mathcal{B}}$ the coordinates of \vec{x} in the basis \mathcal{B} .

Midterm 3. Your initials: _____

You do not need to justify your reasoning for questions on this page.

5. (6 points) Let $\{\vec{u}_1, \vec{u}_2, \vec{u}_3\}$ be an orthogonal basis for \mathbb{R}^3 , where

$$\vec{u}_1 = \begin{pmatrix} 1 \\ -1 \\ 0 \end{pmatrix}, \quad \vec{u}_2 = \begin{pmatrix} -1 \\ -1 \\ 1 \end{pmatrix}, \quad \vec{u}_3 = \begin{pmatrix} 1 \\ 1 \\ 2 \end{pmatrix}.$$

Let \mathcal{W} be a subspace of \mathbb{R}^3 that is spanned by \vec{u}_1 and \vec{u}_2 .

(a) Give an orthonormal basis for \mathcal{W}^\perp .

(b) What is the closest vector in \mathcal{W} to the vector $\vec{y} = \begin{pmatrix} 1 \\ 0 \\ 2 \end{pmatrix}$?

(c) Give a vector $\vec{x} \in \mathbb{R}^3$ that satisfies all of the following conditions:

- \vec{x} is orthogonal to \vec{u}_3 .
- $\text{Proj}_{\mathcal{L}_1} \vec{x} = 2\vec{u}_1$, where $\mathcal{L}_1 = \text{span}\{\vec{u}_1\}$.
- $\text{Proj}_{\mathcal{L}_2} \vec{x} = 3\vec{u}_2$, where $\mathcal{L}_2 = \text{span}\{\vec{u}_2\}$.

Midterm 3. Your initials: _____

6. (6 points) **Show work** on this page with work under the problem, and **your answer in the box**.

$$\text{Let } A = \begin{bmatrix} 1 & 0 & 0 \\ 1 & 2 & 0 \\ -1 & 0 & 2 \end{bmatrix}.$$

(i) List the eigenvalues of A .

(ii) Find an invertible matrix P and a diagonal matrix D such that $A = PDP^{-1}$. If this is not possible, write NP.

$$P = \begin{bmatrix} & & \\ & & \\ & & \end{bmatrix} \quad D = \begin{bmatrix} & & \\ & & \\ & & \end{bmatrix}$$

Midterm 3. Your initials: _____

7. (6 points) **Show work** on this page with work under the problem, and **your answer in the box**.

Find an orthogonal basis of the subspace spanned by the set of vectors shown below.

$$\left\{ \begin{bmatrix} 1 \\ 0 \\ -1 \\ 0 \end{bmatrix}, \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \end{bmatrix}, \begin{bmatrix} 1 \\ 1 \\ 0 \\ 0 \end{bmatrix} \right\}.$$

Note: In order to receive full credit you must clearly show all steps of the Gram-Schmidt process applied to the vectors.



Midterm 3. Your initials: _____

8. (8 points) *Show work on this page with work under the problem, and your answer in the box.*

In this problem, you will use the least-squares method to find the values α and β which best fit the curve

$$y = \alpha \cdot \frac{1}{1+x^2} + \beta$$

to the data points $(-1, 1)$, $(0, -1)$, $(1, 0)$ using the parameters α and β .

(i) What is the augmented matrix for the linear system of equations associated to this least squares problem?

(ii) What is the augmented matrix for the normal equations for this system.

(iii) Find a least-squares solution to the linear system from (i) to determine the parameters α and β of the best fitting curve.

$$\alpha = \boxed{} \quad \beta = \boxed{}$$

Math 1554 Linear Algebra Spring 2023

Midterm 3 Make-up

PLEASE PRINT YOUR NAME CLEARLY IN ALL CAPITAL LETTERS

Name: _____ GTID Number: _____

Student GT Email Address: _____@gatech.edu

Section Number (e.g. A3, G2, etc.) _____ TA Name _____

Circle your instructor:

Prof Kim Prof Barone Prof Schroeder Prof Kumar

Student Instructions

- **Show your work** and justify your answers for all questions unless stated otherwise.
- **Organize your work** in a reasonably neat and coherent way.
- **Simplify your answers** unless explicitly stated otherwise.
- **Fill in circles** completely. Do not use check marks, X's, or any other marks.
- Calculators, notes, cell phones, books are not allowed.
- Use dark and clear writing: your exam will be scanned into a digital system.
- Exam pages are double sided. Be sure to complete both sides.
- Leave a 1 inch border around the edges of exams.
- The last page is for scratch work. Please use it if you need extra space.
- This exam has 8 pages of questions.

Midterm 3 Make-up. Your initials: _____

You do not need to justify your reasoning for questions on this page.

1. (a) (6 points) Suppose A is a real $m \times n$ matrix and $\vec{b} \in \mathbb{R}^m$ unless otherwise stated. Select **true** if the statement is true for all choices of A and \vec{b} . Otherwise, select **false**.

true false

- For any line $L \in \mathbb{R}^2$ passing through the origin, the matrix corresponding to the transformation that reflects across the line L must always be diagonalizable.
- If A and B are $n \times n$ orthogonal matrices, then AB is also $n \times n$ and orthogonal.
- If A is the reduced row echelon form (RREF) of B and A is diagonalizable, then B is diagonalizable.
- If $\vec{b} \in \text{Col}(A)$, then the least squares solution to the linear system $A\vec{x} = \vec{b}$ is unique.
- For any rectangular $m \times n$ matrix A , $(\text{Nul}A)^\perp = \text{Row}A^T A$.
- If the distance of \vec{w} from \vec{v} is equal to the distance of \vec{w} from $-\vec{v}$, then $\vec{w} \cdot \vec{v} = 0$.
-

- (b) (2 points) Indicate whether the following situations are possible or impossible.

possible impossible

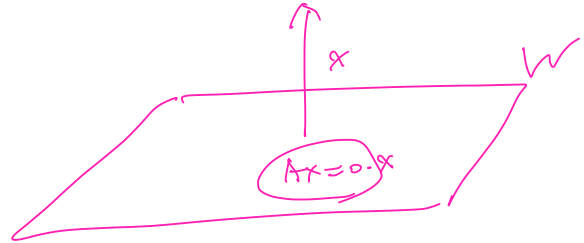
- A diagonal matrix A that is similar to $\begin{pmatrix} 2 & 2 \\ 2 & 2 \end{pmatrix}$.
- An orthogonal matrix A such that $|\det A| \neq 1$.

Midterm 3 Make-up. Your initials: _____

You do not need to justify your reasoning for questions on this page.

(c) (2 points) $\{\vec{v}_1, \vec{v}_2, \vec{v}_3\}$ is an orthonormal basis for subspace V . Fill in circles next to orthogonal bases for V ; leave the other circles empty.

- $\{\vec{v}_1 + \vec{v}_2, \vec{v}_1 + \vec{v}_3, \vec{v}_2 + \vec{v}_3\}$
- $\{\vec{v}_3, 2\vec{v}_1, -\vec{v}_2\}$
- $\{\vec{v}_1 + \vec{v}_2, \vec{v}_1 - \vec{v}_2, \vec{v}_3\}$
- $\{\vec{v}_1, \vec{v}_2 - \vec{v}_3\}$

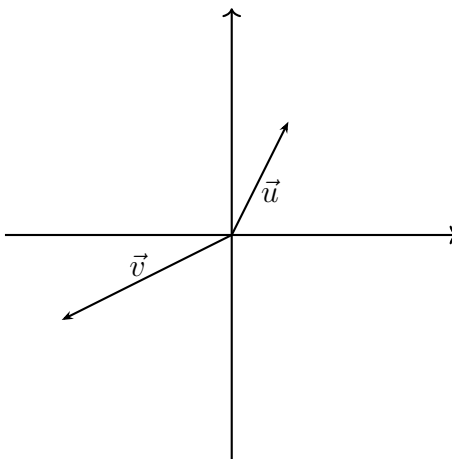


(d) (2 points) Let W be a 3-dimensional subspace of \mathbb{R}^6 and let A be the standard matrix for the orthogonal projection onto W . The following situations are either possible or impossible. Fill in the circles next to the **possible** situations; leave the other circles empty.

- None of the eigenvalues of A are zero.
- A is singular.
- $A\vec{v} = \vec{0}$, for some non-zero vector $v \in W$.
- $\dim \text{Nul} A = \dim \text{Col} A = 3$

$$\begin{aligned} \text{Nul}(A) &= W^\perp \\ \text{Col}(A) &= W \end{aligned}$$

2. (1 point) In the graph below, sketch $\text{proj}_{\vec{v}}(\vec{u})$.



Math 1554 Linear Algebra, Midterm 3 Make-up. Your initials: _____

You do not need to justify your reasoning for questions on this page.

3. (9 points) Fill in the blanks.

(a) If A is 15×17 and $\dim(\text{Col}(A)^\perp) = 10$, the rank of A is .

(b) The distance between vector $\vec{u} = \begin{pmatrix} 4 \\ 5 \end{pmatrix}$ and subspace $W = \text{Span}(\vec{v})$, where $\vec{v} = \begin{pmatrix} 0 \\ 1 \end{pmatrix}$ is equal to .

(c) If $\vec{v}_1 = \begin{pmatrix} 1 \\ -1 \end{pmatrix}$ and $\vec{v}_2 = \begin{pmatrix} 1 \\ 1 \end{pmatrix}$, then $v_1 v_2^T$ is the matrix $\begin{pmatrix} & \\ & \end{pmatrix}$.

(d) The distance between the vector $\vec{u} = \begin{pmatrix} 0 \\ -5 \\ 2 \end{pmatrix}$ and $\vec{v} = \begin{pmatrix} -4 \\ -1 \\ 8 \end{pmatrix}$ is equal to .

(e) If $W = \text{Span} \left\{ \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix} \right\}$, then $\dim W^\perp =$.

Math 1554 Linear Algebra, Midterm 3 Make-up. Your initials: _____

You do not need to justify your reasoning for questions on this page.

4. (4 points) If possible, give examples of the following. If it is not possible, write NP.

(a) A 4×5 matrix A with $\text{Col}A = \text{span}\{[1 \ 1 \ 1 \ 1]^T\}$, that satisfies $\dim((\text{Row}A)^\perp) = 4$.

$$A = \begin{pmatrix} & & & & \\ & & & & \\ & & & & \\ & & & & \end{pmatrix}$$

(b) A 2×3 matrix such that $\text{Col}(A)^\perp$ is spanned by $\begin{pmatrix} 1 \\ 2 \end{pmatrix}$.

$$A = \begin{pmatrix} & & \\ & & \end{pmatrix}$$

(c) A non-zero vector, \vec{w} , whose projection onto the $W = \text{span}\left\{\begin{pmatrix} 1 \\ 0 \\ 3 \end{pmatrix}, \begin{pmatrix} 0 \\ 1 \\ 2 \end{pmatrix}\right\}$ is the zero vector.

$$\vec{w} = \begin{pmatrix} \\ \\ \end{pmatrix}$$

(d) A 3×2 matrix A that is in echelon form, has QR factorization $A = QR$, and $A = Q$.

$$A = \begin{pmatrix} & \\ & \\ & \end{pmatrix}$$

5. (2 points) W is the subspace spanned by $\vec{u} = \begin{pmatrix} 2 \\ 0 \\ 1 \end{pmatrix}$. Give a basis for W^\perp .



Math 1554 Linear Algebra, Midterm 3 Make-up. Your initials: _____

6. (5 points) **Show all work for problems on this page.** Let $W = \text{Nul}(A)$ where

$$A = \begin{bmatrix} 3 & 1 & -1 & 1 \\ 1 & -1 & 1 & -1 \end{bmatrix} \quad \text{and} \quad \vec{y} = \begin{bmatrix} 3 \\ 1 \\ 5 \\ 1 \end{bmatrix}.$$

(a) Find $\text{proj}_{W^\perp}(\vec{y})$. *Please box your answer.*

(b) Find $\vec{y} = \vec{u} + \vec{v}$ where $\vec{u} \in W$ and $\vec{v} \in W^\perp$. *Please box your answer.*

Math 1554 Linear Algebra, Midterm 3 Make-up. Your initials: _____

7. (4 points) **Show all work for problems on this page.** Compute the equation of the line $y = \beta_0 + \beta_1 x$ of best fit using the least-squares method for the data below.
Please box your answer.

x	-1	0	1
y	0	1	5

Math 1554 Linear Algebra, Midterm 3 Make-up. Your initials: _____

8. (5 points) **Show all work for problems on this page.** Let $\mathcal{B} = \{x_1, x_2, x_3\}$ be a basis for a subspace W of \mathbb{R}^4 where

$$\vec{x}_1 = \begin{pmatrix} -1 \\ 3 \\ 1 \\ 1 \end{pmatrix}, \quad \vec{x}_2 = \begin{pmatrix} 6 \\ -8 \\ -2 \\ -4 \end{pmatrix}, \quad \vec{x}_3 = \begin{pmatrix} 6 \\ 3 \\ 6 \\ -3 \end{pmatrix}.$$

Apply the Gram–Schmidt process to the set $\{\vec{x}_1, \vec{x}_2, \vec{x}_3\}$ to find an orthonormal basis $\mathcal{H} = \{\vec{y}_1, \vec{y}_2, \vec{y}_3\}$ for the subspace W . *Please box your answer.*

Math 1554 Linear Algebra, Midterm 3 Make-up. Your initials: _____

9. (4 points) **Show all work for problems on this page.** If $A = \begin{pmatrix} -5 & -5 \\ 5 & -5 \end{pmatrix}$ has eigenvalues λ_1, λ_2 with corresponding eigenvectors v_1, v_2 , and $\lambda_1 = -5 + 5i$, find λ_2, v_1, v_2 .

$$\lambda_2 = \boxed{}$$

$$\vec{v}_1 = \boxed{}$$

$$\vec{v}_2 = \boxed{}$$

10. (4 points) Find matrices P and D such that $A = PDP^{-1}$ where D is a diagonal matrix and P is an invertible matrix.

$$A = \begin{bmatrix} 1 & 1 \\ 0 & 3 \end{bmatrix}$$

$$P = \boxed{}$$

$$D = \boxed{}$$

Math 1554 Linear Algebra Fall 2022

Midterm 3 Make-up

PLEASE PRINT YOUR NAME CLEARLY IN ALL CAPITAL LETTERS

Name: _____ GTID Number: _____

Student GT Email Address: _____@gatech.edu

Section Number (e.g. A3, G2, etc.) _____ TA Name _____

Circle your instructor:

Prof Vilaca Da Rocha Prof Kafer Prof Barone Prof Wheeler
Prof Blumenthal Prof Sun Prof Shirani

Student Instructions

- **Show your work** and justify your answers for all questions unless stated otherwise.
- **Organize your work** in a reasonably neat and coherent way.
- **Simplify your answers** unless explicitly stated otherwise.
- **Fill in circles** completely. Do not use check marks, X's, or any other marks.
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- Leave a 1 inch border around the edges of exams.
- The last page is for scratch work. Please use it if you need extra space.
- This exam has 7 pages of questions.

Midterm 3 Make-up. Your initials: _____

You do not need to justify your reasoning for questions on this page.

1. (a) (8 points) Suppose A is an $m \times n$ matrix and $\vec{b} \in \mathbb{R}^m$ unless otherwise stated. Select **true** if the statement is true for all choices of A and \vec{b} . Otherwise, select **false**.

true false

- A matrix $A \in \mathbb{R}^{n \times n}$ and its transpose A^T have the same eigenvectors.
- The line of best fit $y = \beta_0 + \beta_1 x$ for the points $(1, 1)$, $(2, 1)$, and $(3, 1)$ is unique.
- If the vectors \vec{u} and \vec{v} are orthogonal then $\|\vec{u} + \vec{v}\| = \|\vec{u}\| + \|\vec{v}\|$.
- A triangular matrix A is diagonalizable if and only if A is invertible.
- If $A = PDP^{-1}$ where D is a diagonal matrix, then D and A have the same eigenvectors.
- If $\vec{y} \in \mathbb{R}^n$ is a nonzero vector and W is a subspace of \mathbb{R}^n , then $\text{proj}_W(\vec{y})$ is in W .
- If $\vec{y} \in \mathbb{R}^n$ is a nonzero vector and W is a subspace of \mathbb{R}^n , then $\|\vec{y} - \text{proj}_W(\vec{y})\|$ is the shortest distance between W and \vec{y} .
- If W is a subspace of \mathbb{R}^n and $\vec{y} \in \mathbb{R}^n$ such that $\vec{y} \cdot \vec{w} = 0$ for some vector $\vec{w} \in W$, then $\vec{y} \in W^\perp$.
-

- (b) (4 points) Indicate whether the following situations are possible or impossible.

possible impossible

- A 3×3 real matrix A such that A has eigenvalues $2, 3, 2i + 3$.
- An $m \times n$ matrix U where $U^T U = I_n$ and $n > m$.
- A 2-dimensional subspace W of \mathbb{R}^3 and a vector $\vec{y} \in W$ such that $\|\vec{v}_1 - \vec{y}\| = \|\vec{v}_2 - \vec{y}\|$ where $\vec{v}_1, \vec{v}_2 \in W^\perp$ and $\vec{v}_1 \neq \vec{v}_2$.
- A vector $\vec{y} \in \mathbb{R}^3$ and a subspace W in \mathbb{R}^3 such that $\vec{y} = \vec{w} + \vec{z}$ where \vec{w} is in W , but \vec{z} is not in W^\perp .
-

Midterm 3 Make-up. Your initials: _____

You do not need to justify your reasoning for questions on this page.

(c) (2 points) An $m \times n$ matrix $A = [\vec{a}_1 \ \cdots \ \vec{a}_n]$ has non-zero orthogonal columns and $A^T A = 2I_n$. Which of the following statements is FALSE?

- $(A\vec{x}) \cdot (A\vec{y}) = \vec{x} \cdot \vec{y}$ for every \vec{x} and \vec{y} in \mathbb{R}^n .
- $n \leq m$.
- If we apply the Gram-Schmidt process to $\{\vec{a}_1, \dots, \vec{a}_n\}$ we obtain the same set $\{\vec{a}_1, \dots, \vec{a}_n\}$.
- If $A = QR$ is the QR factorization of A , then R is a diagonal matrix.

2. (3 points) Using **only** 0's and 1's in your answers, give an example of 2×2 matrices that satisfy: A is invertible but not diagonalizable, and B is diagonalizable but not invertible.

$$A = \begin{pmatrix} & \\ & \end{pmatrix} \quad B = \begin{pmatrix} & \\ & \end{pmatrix}$$

Midterm 3 Make-up. Your initials: _____

You do not need to justify your reasoning for questions on this page.

3. (8 points) Fill in the blanks.

(a) Suppose \vec{u} and \vec{v} are orthogonal vectors in \mathbb{R}^n and that \vec{v} is a unit vector.

If $(3\vec{u} + \vec{v}) \cdot (\vec{u} + 4\vec{v}) = 31$, determine the length of \vec{u} .

$\|\vec{u}\| =$

(b) The normal equations for the least-squares solution to $A\vec{x} = \vec{b}$ are given by:

(c) Compute the length (magnitude) of the vector \vec{y} .

$$\vec{y} = \begin{pmatrix} \frac{1}{\sqrt{3}} & 0 \\ \frac{1}{\sqrt{3}} & -\frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{2}} \end{pmatrix} \begin{pmatrix} 4 \\ 3 \end{pmatrix}$$

$\|\vec{y}\| =$

(d) Let $A = \begin{bmatrix} 3 & 3 \\ -3 & 3 \end{bmatrix}$. The vector $\vec{v} = \begin{pmatrix} 1+i \\ 1-i \end{pmatrix}$ is an eigenvector of A . Find the associated eigenvalue λ for the eigenvector \vec{v} of A .

$\lambda =$

$$A \cdot \vec{v} = \begin{bmatrix} 3 & 3 \\ -3 & 3 \end{bmatrix} \begin{bmatrix} 1+i \\ 1-i \end{bmatrix}$$

$$= 3 \cdot \begin{bmatrix} 1 & 1 \\ -1 & 1 \end{bmatrix} \begin{bmatrix} 1+i \\ 1-i \end{bmatrix} = 3 \cdot \begin{bmatrix} 2 \\ -2i \end{bmatrix} = \lambda \cdot \begin{bmatrix} 1+i \\ 1-i \end{bmatrix}$$

$$6 = \lambda \cdot (1+i)$$

$$-6i = \lambda (1-i)$$

$$6 = \lambda \cdot (1+i)$$

$$\lambda = \frac{6(1-i)}{(1+i)(1-i)}$$

$$= \frac{6}{2} \cdot (1-i) = 3(1-i)$$

Midterm 3 Make-up. Your initials: _____

You do not need to justify your reasoning for questions on this page.

4. (4 points) Fill in the blanks.

(a) Let $W = \text{span} \left\{ \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix} \right\}$ and let $\vec{y} = \begin{pmatrix} 1 \\ 2 \\ 3 \end{pmatrix}$. Calculate the projection of \vec{y} onto the subspace W , and find the distance from \vec{y} to W .

$\text{proj}_W(\vec{y}) =$

$\text{dist}(\vec{y}, W) =$

(b) Let $W = \text{span} \left\{ \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix}, \begin{pmatrix} 1 \\ 1 \\ 0 \end{pmatrix} \right\}$, $L = \text{span} \left\{ \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix} \right\}$. Find **all** vectors $\vec{u} \in L$ such that the distance from \vec{u} to W is equal to 2.

Midterm 3 Make-up. Your initials: _____

5. (6 points) **Show all work for problems on this page.**

One of the eigenvalues of the matrix A is $\lambda = 1$. Diagonalize the matrix.

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

$P =$

$D =$

6. (3 points) Find a matrix $A \in \mathbb{R}^{2 \times 2}$ such that \vec{v}_1 is an eigenvector of A with eigenvalue $\lambda_1 = 2$, and \vec{v}_2 is an eigenvector of A with eigenvalue $\lambda_2 = 3$.

$$\vec{v}_1 = \begin{pmatrix} 2 \\ 3 \end{pmatrix}, \quad \vec{v}_2 = \begin{pmatrix} 1 \\ 1 \end{pmatrix}.$$

$A =$

Midterm 3 Make-up. Your initials: _____

7. (4 points) **Show all work for problems on this page.**

Let $\mathcal{B} = \{\vec{x}_1, \vec{x}_2, \vec{x}_3\}$ be a basis for a subspace W of \mathbb{R}^4 , where

$$\vec{x}_1 = \begin{pmatrix} -1 \\ 1 \\ -1 \\ 1 \end{pmatrix}, \quad \vec{x}_2 = \begin{pmatrix} 1 \\ 2 \\ -2 \\ 1 \end{pmatrix}, \quad \vec{x}_3 = \begin{pmatrix} -1 \\ -1 \\ 0 \\ 2 \end{pmatrix}.$$

(a) Apply the Gram-Schmidt process to the set of vectors $\{\vec{x}_1, \vec{x}_2, \vec{x}_3\}$ to find an orthogonal basis $\mathcal{H} = \{\vec{v}_1, \vec{v}_2, \vec{v}_3\}$ for W . Clearly show all steps of the Gram-Schmidt process.

$\mathcal{H} =$

(b) In the space below, **check** that the vectors in the basis \mathcal{H} form an orthogonal set.

Midterm 3 Make-up. Your initials: _____

8. (4 points) **Show all work for problems on this page.**

If A has the following QR factorization

$$A = \frac{1}{2} \begin{pmatrix} 1 & 1 \\ -1 & 1 \\ 1 & 1 \\ 1 & -1 \end{pmatrix} \begin{pmatrix} 1 & -1 \\ 0 & 2 \end{pmatrix}, \text{ and } \vec{b} = \begin{pmatrix} 1 \\ 2 \\ 1 \\ 2 \end{pmatrix},$$

compute the least-square solution to the equation $A\vec{x} = \vec{b}$.

$$\hat{x} = \boxed{\phantom{\begin{matrix} \\ \\ \\ \end{matrix}}}$$

9. (4 points) Compute the least squares line $y = c_1x + c_2$ that best fits the data

$$\begin{array}{c|ccc} x & -1 & 0 & 1 \\ \hline y & 1 & -2 & 2 \end{array}$$

$$\boxed{\phantom{\begin{matrix} \\ \\ \\ \end{matrix}}}$$

Math 1554 Linear Algebra Spring 2022

Midterm 3 Make-up

PLEASE PRINT YOUR NAME CLEARLY IN ALL CAPITAL LETTERS

Name: _____ GTID Number: _____

Student GT Email Address: _____@gatech.edu

Section Number (e.g. A3, G2, etc.) _____ TA Name _____

Circle your instructor:

Prof Barone Prof Shirani Prof Simone Prof Timko

Student Instructions

- **Show your work** and justify your answers for all questions unless stated otherwise.
- **Organize your work** in a reasonably neat and coherent way.
- **Simplify your answers** unless explicitly stated otherwise.
- **Fill in circles** completely. Do not use check marks, X's, or any other marks.
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- Leave a 1 inch border around the edges of exams.
- The last page is for scratch work. Please use it if you need extra space.
- This exam has 7 pages of questions.

Midterm 3 Make-up. Your initials: _____

You do not need to justify your reasoning for questions on this page.

1. (a) (8 points) Suppose A is an $m \times n$ matrix and $\vec{b} \in \mathbb{R}^m$ unless otherwise stated. Select **true** if the statement is true for all choices of A and \vec{b} . Otherwise, select **false**.

true false

-
- | | | |
|-----------------------|-----------------------|--|
| <input type="radio"/> | <input type="radio"/> | The matrix $\begin{bmatrix} 1 & 0 & -1 \\ 0 & 2 & 0 \\ 0 & 0 & 1 \end{bmatrix}$ is diagonalizable. |
| <input type="radio"/> | <input type="radio"/> | If W is the subspace of \mathbb{R}^3 spanned by $\begin{pmatrix} 1 \\ 2 \\ -1 \end{pmatrix}$ and $\begin{pmatrix} 3 \\ 0 \\ 0 \end{pmatrix}$, then $\begin{pmatrix} 0 \\ 1 \\ 2 \end{pmatrix}$ is a vector in W^\perp . |
| <input type="radio"/> | <input type="radio"/> | If U is a 3×2 matrix with orthonormal columns, then $(UU^T)^2 = UU^T$. |
| <input type="radio"/> | <input type="radio"/> | If $A^T A = 3I$, then A has orthogonal columns. |
| <input type="radio"/> | <input type="radio"/> | Assume $n \neq m$. If $A = QR$ is the QR factorization of $A \in \mathbb{R}^{m \times n}$, then $Q \in \mathbb{R}^{m \times n}$ and $R \in \mathbb{R}^{n \times n}$. |
| <input type="radio"/> | <input type="radio"/> | If $A = QR$ is a QR factorization of A , then $A^T A = R^T R$. |
| <input type="radio"/> | <input type="radio"/> | If \hat{x} and \hat{y} are least-squares solutions of $A\vec{x} = \vec{b}$, then $\hat{x} - \hat{y} \in \text{Nul}(A)$. |
| <input type="radio"/> | <input type="radio"/> | Suppose A is such that for every \vec{b} the system $A\vec{x} = \vec{b}$ has a unique least-squares solution. Then $\det(A^T A) \neq 0$. |
-

- (b) (4 points) Indicate whether the following situations are possible or impossible.

possible impossible

-
- | | | |
|-----------------------|-----------------------|---|
| <input type="radio"/> | <input type="radio"/> | A is a real 5×5 diagonalizable matrix with exactly three distinct real eigenvalues whose geometric multiplicities are 1, 1, and 2, respectively. |
| <input type="radio"/> | <input type="radio"/> | \vec{u} and \vec{v} are nonzero orthogonal vectors such that $\ \vec{u} + \vec{v}\ ^2 < \ \vec{u}\ ^2 + \ \vec{v}\ ^2$. |
| <input type="radio"/> | <input type="radio"/> | The distance between a vector $\vec{b} \in \mathbb{R}^m$ and the column space of a matrix $A \in \mathbb{R}^{m \times n}$ is nonzero, and the linear system $A\vec{x} = \vec{b}$ has a unique least squares solution. |
| <input type="radio"/> | <input type="radio"/> | \mathcal{W} is a 2-dimensional subspace of \mathbb{R}^3 , and there exists a linearly independent set of vectors $\{\vec{x}, \vec{y}\}$ in \mathbb{R}^3 such that $\text{Proj}_{\mathcal{W}} \vec{x} = 0$ and $\text{Proj}_{\mathcal{W}} \vec{y} = 0$. |
-

Midterm 3 Make-up. Your initials: _____

You do not need to justify your reasoning for questions on this page.

- (c) (2 points) The standard matrix of a linear transformation $T : \mathbb{R}^3 \rightarrow \mathbb{R}^3$ has orthonormal columns. Which one of the following statements is **false**?

Choose only one.

- If $T(\vec{x}) = A\vec{x}$ then $\det(A) = 1$.
- $T(\vec{x}) \cdot T(\vec{y}) = T(\vec{x} \cdot \vec{y})$ for all \vec{x}, \vec{y} in \mathbb{R}^3
- $\|T(\vec{x})\| = \|\vec{x}\|$ for all \vec{x} in \mathbb{R}^3 .
- T is onto.

2. (2 points) Suppose that, in the QR factorization of A , we have Q as given below. Find R .

$$A = \begin{bmatrix} -1 & 2 \\ 1 & 2 \\ 1 & 2 \\ -1 & -2 \end{bmatrix} \quad Q = \frac{1}{2} \begin{bmatrix} -1 & \sqrt{3} \\ 1 & 1/\sqrt{3} \\ 1 & 1/\sqrt{3} \\ -1 & -1/\sqrt{3} \end{bmatrix}$$

Note: Please fill in the blanks and do not place values in front of the matrix for this problem.

$$R = \begin{bmatrix} \underline{\hspace{1cm}} & \underline{\hspace{1cm}} \\ \underline{\hspace{1cm}} & \underline{\hspace{1cm}} \end{bmatrix}$$

Midterm 3 Make-up. Your initials: _____

You do not need to justify your reasoning for questions on this page.

3. (2 points) Using **only** 0's and 1's in your answer, give an example of a 2×2 matrix that is not invertible and not diagonalizable. If not possible, write NP.

$$\left(\begin{array}{cc} & \\ & \end{array} \right)$$

4. (6 points) Fill in the blanks.

- (a) Let $\vec{u}, \vec{v} \in \mathbb{R}^n$ be vectors each with length 2 and suppose $u \cdot v = -1$. Determine the length of the vector $3\vec{u} + \vec{v}$.
- (b) Suppose A is a 5×7 matrix such that $\dim(\text{Nul } A)^\perp = 4$. Determine the dimension of the orthogonal complement of the column space of A .
- (c) Suppose $\mathcal{B} = \{\vec{v}_1, \vec{v}_2\}$ is an orthogonal basis for a subspace \mathcal{W} of \mathbb{R}^n , and \vec{x} belongs to the subspace \mathcal{W} . Suppose also that

$$\vec{v}_1 \cdot \vec{x} = 4, \vec{v}_2 \cdot \vec{x} = -3, \vec{v}_1 \cdot \vec{v}_1 = 2, \text{ and } \vec{v}_2 \cdot \vec{v}_2 = 6.$$

Find $[\vec{x}]_{\mathcal{B}}$ the coordinates of \vec{x} in the basis \mathcal{B} .

Midterm 3 Make-up. Your initials: _____

You do not need to justify your reasoning for questions on this page.

5. (6 points) Let $\{\vec{u}_1, \vec{u}_2, \vec{u}_3\}$ be an orthogonal basis for \mathbb{R}^3 , where

$$\vec{u}_1 = \begin{pmatrix} 2 \\ 1 \\ 1 \end{pmatrix}, \quad \vec{u}_2 = \begin{pmatrix} 0 \\ 1 \\ -1 \end{pmatrix}, \quad \vec{u}_3 = \begin{pmatrix} 1 \\ -1 \\ -1 \end{pmatrix}.$$

Let \mathcal{W} be a subspace of \mathbb{R}^3 that is spanned by \vec{u}_1 and \vec{u}_2 .

(a) Give an orthonormal basis for \mathcal{W}^\perp .

(b) What is the closest vector in \mathcal{W} to the vector $\vec{y} = \begin{pmatrix} 1 \\ 0 \\ 2 \end{pmatrix}$?

(c) Give a vector $\vec{x} \in \mathbb{R}^3$ that satisfies all of the following conditions:

- \vec{x} is orthogonal to \vec{u}_3 .
- $\text{Proj}_{\mathcal{L}_1} \vec{x} = 2\vec{u}_1$, where $\mathcal{L}_1 = \text{span}\{\vec{u}_1\}$.
- $\text{Proj}_{\mathcal{L}_2} \vec{x} = 3\vec{u}_2$, where $\mathcal{L}_2 = \text{span}\{\vec{u}_2\}$.

Midterm 3 Make-up. Your initials: _____

6. (6 points) **Show work** on this page with work under the problem, and **your answer in the box**.

$$\text{Let } A = \begin{bmatrix} 2 & 0 & 0 \\ -1 & 1 & 0 \\ 2 & 0 & 1 \end{bmatrix}.$$

(i) List the eigenvalues of A .

(ii) Find an invertible matrix P and a diagonal matrix D such that $A = PDP^{-1}$. If this is not possible, write NP.

$$P = \begin{bmatrix} & & \\ & & \\ & & \end{bmatrix} \quad D = \begin{bmatrix} & & \\ & & \\ & & \end{bmatrix}$$

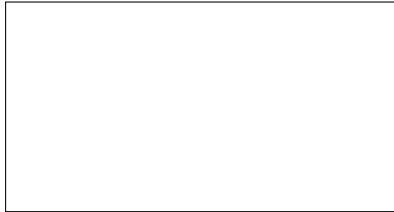
Midterm 3 Make-up. Your initials: _____

7. (6 points) **Show work** on this page with work under the problem, and **your answer in the box**.

Find an orthogonal basis of the subspace spanned by the set of vectors shown below.

$$\left\{ \begin{bmatrix} 1 \\ 0 \\ 1 \\ 0 \end{bmatrix}, \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \end{bmatrix}, \begin{bmatrix} 1 \\ 1 \\ -1 \\ 0 \end{bmatrix} \right\}.$$

Note: In order to receive full credit you must clearly show all steps of the Gram-Schmidt process applied to the vectors.



Midterm 3 Make-up. Your initials: _____

8. (8 points) *Show work on this page with work under the problem, and your answer in the box.*

In this problem, you will use the least-squares method to find the values α and β which best fit the curve

$$y = \alpha \cdot 2^{-x^2} + \beta x$$

to the data points $(-1, 2)$, $(0, 0)$, $(1, 1)$ using the parameters α and β .

(i) What is the augmented matrix for the linear system of equations associated to this least squares problem?

(ii) What is the augmented matrix for the normal equations for this system.

(iii) Find a least-squares solution to the linear system from (i) to determine the parameters α and β of the best fitting curve.

$$\alpha = \boxed{} \quad \beta = \boxed{}$$