University of Toronto
FACULTY OF APPLIED SCIENCE AND ENGINEERING
FINAL EXAMINATION, DECEMBER, 2009
First Year - CHE, CIV, CPE, ELE, ENG, IND, LME, MEC, MMS

MAT188H1F - LINEAR ALGEBRA
Exam Type: A

SURNAME: (as on your T-card)   _____

YOUR FULL NAME: _____

STUDENT NUMBER: _____

SIGNATURE: _____

Examiners:
D. Burbulla
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Calculators Permitted: Casio 260, Sharp 520 or TI 30.

Notation: as in the textbook, 0 represents the zero vector, the zero matrix, or the zero number, depending on context. Also, if A is an $n \times n$ matrix, $E_\lambda(A) = \{X \in \mathbb{R}^n \mid AX = \lambda X\}$.

INSTRUCTIONS: Attempt all questions. Present your solutions in the space provided. Use the backs of the sheets if you need more space. Do not tear any pages from this exam. Make sure your exam contains 10 pages.

MARKS: Questions 1 through 6 are Multiple Choice; circle the single correct choice for each question. Each correct choice is worth 4 marks.

Question 7 is worth 10 marks; 2 for each part.

Questions 8, 9 and 10 are each worth 10 marks.

Questions 11, 12 and 13 are each worth 12 marks.

TOTAL MARKS: 100

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1. The values of a for which the matrix $\begin{bmatrix} 6 & 0 & a \\ 0 & 2 & 0 \\ a & 0 & 6 \end{bmatrix}$ is not invertible, are

   (a) $a = \pm 3$

   (b) $a = \pm 2$

   (c) $a = \pm 6$

   (d) $a = \pm 9$

2. If A and B are 3×3 matrices such that $\det(A) = 2$ and $\det(B) = -3$, then the value of $\det(A^2 B^{-1} A^T B^3)$ is

   (a) -72

   (b) 72

   (c) -108

   (d) 108

3. The characteristic polynomial of the matrix $A = \begin{bmatrix} a & b \\ c & d \end{bmatrix}$ is

   (a) $C_A(x) = x^2 - (a + b)x + c + d$

   (b) $C_A(x) = x^2 - (a + d)x + cb - ad$

   (c) $C_A(x) = x^2 + (a + b)x + ad - bc$

   (d) $C_A(x) = x^2 - (a + d)x + ad - bc$

4. If $\vec{u} \cdot \vec{v} \times \vec{w} = 10$, then the value of $3\vec{v} \cdot u \times \vec{w}$ is

(a) 10

(b) 30

(c) −10.

(d) −30

5. Suppose two lines in space are both parallel to the vector $\vec{d}$, one line passes through the point X_1, and the other line passes through the point X_2. The minimum distance between these two parallel lines is given by

(a) $\left\| \overrightarrow{X_1 X_2} \right\|$

(b) $\left\| \text{proj}_{\vec{d}} \left(\overrightarrow{X_1 X_2} \right) \right\|$

(c) $\sqrt{ \left\| \overrightarrow{X_1 X_2} \right\|^2 - \left\| \text{proj}_{\vec{d}} \left(\overrightarrow{X_1 X_2} \right) \right\|^2 }$

(d) $\sqrt{ \left\| \text{proj}_{\vec{d}} \left(\overrightarrow{X_1 X_2} \right) \right\|^2 - \left\| \overrightarrow{X_1 X_2} \right\|^2 }$

6. Suppose $T\left(\begin{bmatrix} x \\ y \end{bmatrix} \right) = \begin{bmatrix} 2x + 7y \\ 8x + 6y \end{bmatrix}$. Then the area of the image of the unit square is

(a) −68

(b) 68

(c) −44

(d) 44

7. Decide if the following statements are True or False, and give a brief, concise justification for your choice. Circle your choice.

(a) span $\left\{ \begin{bmatrix} 1 \\ 0 \\ 1 \end{bmatrix}, \begin{bmatrix} 1 \\ 4 \\ 3 \end{bmatrix}, \begin{bmatrix} 3 \\ 1 \\ 1 \end{bmatrix}, \begin{bmatrix} 5 \\ 1 \\ 6 \end{bmatrix} \right\} = \mathbb{R}^3.$ **True** or **False**

(b) If U is a subspace of $\mathbb{R}^6$ and $\dim U = 4$ then $\dim U^\perp = 2$.   **True** or **False**

(c) If A is an invertible matrix then $\lambda = 0$ is an eigenvalue of A.   **True** or **False**

(d) If $\{X, Y, Z\}$ is linearly independent, then $\{X, Y\}$ is also linearly independent.

True or **False**

(e) For any $n \times n$ invertible matrix A, $\operatorname{adj}(A^{-1}) = (\operatorname{adj} A)^{-1}$.   **True** or **False**

8. Given that the reduced row-echelon form of

$$A = \begin{bmatrix} 1 & -1 & 1 & 3 & 1 \\ 1 & -1 & 2 & 0 & 1 \\ 2 & -2 & 3 & 3 & 2 \\ -1 & 1 & -1 & -1 & 1 \end{bmatrix} \text{ is } R = \begin{bmatrix} 1 & -1 & 0 & 0 & -5 \\ 0 & 0 & 1 & 0 & 3 \\ 0 & 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix},$$

state the rank of A, and find a basis for each of the following: the row space of A, the column space of A, and the null space of A.

9. Let A be an $n \times n$ matrix. Let $U = \{X \in \mathbb{R}^n \mid A^2X = AX\}$.

(a) [5 marks] Show that U is a subspace of $\mathbb{R}^n$.

(b) [5 marks] Show that if A is diagonalizable then $\dim U = \dim E_0(A) + \dim E_1(A)$.

10. Find a basis for $U^{\perp}$ if

$$U = \text{span}\left\{[\,1 \quad 0 \quad 1 \quad 3 \quad 1\,]^T, [\,1 \quad 0 \quad 2 \quad 0 \quad 1\,]^T, [\,1 \quad -1 \quad 0 \quad 1 \quad 1\,]^T\right\}.$$

11. Find an orthogonal matrix P and a diagonal matrix D such that $D = P^T A P$, if

$$A = \begin{bmatrix} 5 & -2 & 4 \\ -2 & 8 & 2 \\ 4 & 2 & 5 \end{bmatrix}.$$

12. Let $U = \text{span} \left\{ \begin{bmatrix} 0 & 1 & 0 & -1 \end{bmatrix}^T, \begin{bmatrix} 1 & 0 & 0 & 1 \end{bmatrix}^T, \begin{bmatrix} 0 & 0 & 1 & -1 \end{bmatrix}^T \right\}$;

let $X = \begin{bmatrix} 1 & 1 & 0 & 1 \end{bmatrix}^T$. Find:

(a) [6 marks] an orthogonal basis of U.

(b) [6 marks] $\text{proj}_U(X)$.

13. Find the least squares approximating quadratic for the data points

$$(-1, 0), (0, 2), (1, 1), (1, -1).$$