Math 308L - Autumn 2017
Final Exam
December 14, 2017

Name: ______________________________
Student ID Number: ______________________________

Question	Points	Score
1	12	
2	12	
3	12	
4	12	
5	12	
6	12	
7	12	
Total:	84	

- There are 7 problems on this exam. Be sure you have all 7 problems on your exam.
- The final answer must be left in exact form. Box your final answer.
- You are allowed the TI-30XIIS calculator. It is possible to complete the exam without a calculator.
- You are allowed a single sheet of 2-sided self-written notes.
- You must show your work to receive full credit. A correct answer with no supporting work will receive a zero.
- Use the backsides if you need extra space. Make a note of this if you do.
- Do not cheat. This exam should represent your own work. If you are caught cheating, I will report you to the Community Standards and Student Conduct office.

Conventions:

- I will often denote the zero vector by 0.
- When I define a variable, it is defined for that whole question. The A defined in Question 2 is the same for each part.
- I often use x to denote the vector $(x_1, x_2, \dots, x_n)$. It should be clear from context.
- Sometimes I write vectors as a row and sometimes as a column. The following are the same to me.

$$(1,2,3) \quad \begin{bmatrix}1\\2\\3\end{bmatrix}.$$

- I write the evaluation of linear transformations in a few ways. The following are the same to me.

$$T(1,2,3) \quad T((1,2,3)) \quad T\left(\begin{bmatrix}1\\2\\3\end{bmatrix}\right)$$

1. Give an example of each of the following. If it is not possible, write "NOT POSSIBLE".

   (a) (2 points) Give an example of a 2×3 matrix A and a vector $b \in \mathbb{R}^2$ such that $Ax = b$ has no solutions but $Ax = 0$ has infinitely many solutions.

   (b) (2 points) Give an example of a linear system in 3 variables whose solution space is the intersection of the $x + y + z = 0$ plane and the xy-plane.

   (c) (2 points) Give an example of a 2×2 matrix A such that $A^4 = I_2$ but $A^2 \neq I_2$. If possible, give the matrix A explicitly.

   (d) (2 points) Give an example of 2 linear transformations $T : \mathbb{R}^3 \to \mathbb{R}^3$ and $S : \mathbb{R}^2 \to \mathbb{R}^2$ such that $\text{range}(T) = \ker(S)$.

   (e) (2 points) Give an example of an orthogonal matrix that is not invertible.

   (f) (2 points) Give an example of an diagonalizable matrix that is not orthogonally diagonalizable.

2. Let A be defined by

$$A = \begin{bmatrix} 1 & 2 & 2 \\ 2 & 4 & 4 \\ 0 & 0 & 2 \end{bmatrix}.$$

(a) (4 points) Find a basis for the solution space $Ax = 0$.

(b) (4 points) What is the general solution to $Ax = \begin{bmatrix} 3 \\ 6 \\ -3 \end{bmatrix}$?

(c) (4 points) Is there a vector $y \in \mathbb{R}^3$ such that $Ax = y$ has no solutions? If so, give an example. If not, why not?

3. Let A and B be equivalent matrices defined by

$$A = \begin{bmatrix} -3 & 3 & -1 & -9 & 3 \\ 2 & -2 & 1 & 7 & -1 \\ 4 & -4 & 5 & 23 & 7 \end{bmatrix} \sim \begin{bmatrix} 1 & -1 & 0 & 2 & -2 \\ 0 & 0 & 1 & 3 & 3 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix} = B.$$

(a) (4 points) Find a basis for the solution space of $Ax = 0$.

(b) (4 points) Let a_1, a_2, a_3, a_4, a_5 be the columns of A. Define $C = [a_1\ a_2\ a_3\ a_4]$. What is a particular solution to $Cx = a_5$?

(c) (4 points) Using the same variables as (b), what is the general solution to $Cx = 2a_4 - a_5$?

4. Let S be a subspace of $\mathbb{R}^4$ defined by

$$S = \text{span}\left\{ \begin{bmatrix}1\\1\\1\\1\end{bmatrix}, \begin{bmatrix}1\\1\\0\\0\end{bmatrix}, \begin{bmatrix}0\\0\\1\\1\end{bmatrix} \right\}.$$

(a) (3 points) What is a basis for $(S^\perp)^\perp$?

(b) (3 points) What is a basis for $S^\perp$?

(c) (3 points) Does there exist a rank 2 matrix A such that $\text{null}(A) = S$? If so, give an example. If not, why not?

(d) (3 points) Does there exist a rank 3 matrix A such that $\text{null}(A) = S$? If so, give an example. If not, why not?

5. Let $T : \mathbb{R}^3 \to \mathbb{R}^3$ be the linear transform defined by the following properties:

   - $T(0, 0, 1) = (0, 0, 0)$,
   - If v is in the xy-plane, then v is reflected across the $x + y = 0$ plane.

   There is a matrix A such that $T(x) = Ax$. The goal of this problem is to understand A.

   (a) (3 points) Find a basis $\{u, v, w\}$ where the action of T is well-understood. Give also $T(u), T(v)$, and $T(w)$.

   (b) (3 points) Find the eigenvalues of A and a basis for each eigenspace of A. (Think geometrically.)

   (c) (3 points) What is A? You may express it as product of matrices and their inverses.

   (d) (3 points) What is A^2? Give it explicitly as a single matrix. (Think geometrically.)

6. Let A be the symmetric matrix defined as

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

(a) (3 points) Find the eigenvalues of A and a basis for each eigenspace of A.

(b) (3 points) Find a basis for each of the following subspaces.

- $\text{null}(A)$
- $\text{null}(A - I)$
- $\text{null}(A - 2I)$.

(c) (3 points) Find an orthogonal matrix Q and a diagonal matrix D such that $A = QDQ^{-1}$.

(d) (3 points) Find all $k \in \mathbb{R}$ such that $A - kI_3$ is not invertible.

7. Let $v = (2, 1, 2)$ and $T : \mathbb{R}^3 \to \mathbb{R}^3$ be defined by $T(x) = \text{proj}_v x$.

   (a) (4 points) Find an orthogonal basis for $\mathbb{R}^3$ that contains v. (Hint: first find a basis for $\mathbb{R}^3$ that contains v.)

   (b) (4 points) There exists a matrix A such that $T(x) = Ax$. Find the eigenvalues of A and a basis for each eigenspace of A. (Hint: see part (a).)

   (c) (4 points) Let $e_1 = (1, 0, 0)$. Evaluate the following:

   - Ae_1
   - A^2e_1
   - $A^{100}e_1$